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Aggregate Resources Inventory of McGillivray, East Williams and West Williams Townships

Southern Ontario

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By Staff of the Engineering and Terrain Geology Section,
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Contents

Abstract v

Résumé vi

Introduction 3

Part I — Inventory Methods 4
- Field and Office Methods 4
- Resource Tonnage Calculation Techniques 4
  - Sand and Gravel Resources 4
  - Bedrock Resources 5
  - Units and Definitions 5

Part II — Data Presentation and Interpretation 6
- Map 1: Distribution of Sand and Gravel Deposits 6
  - Deposit Symbol 6
  - Texture Symbol 6
- Map 2: Selected Sand and Gravel Resource Areas 6
  - Site Specific Criteria 7
    - Deposit Size 7
    - Aggregate Quality 7
    - Location and Setting 8
  - Regional Considerations 8
- Map 3: Bedrock Resources 8
  - Selection Criteria 9
  - Selected Resource Areas 9

Part III - Assessment of Aggregate Resources in McGillivray, East Williams and West Williams Townships 10
- Location and Population 10
- Physiography and Surficial Geology 10
- Extractive Activity 11
- Selected Sand and Gravel Resource Areas 11
  - Selected Sand and Gravel Resource Area 1 12
  - Selected Sand and Gravel Resource Area 2 12
  - Selected Sand and Gravel Resource Area 3 12
  - Selected Sand and Gravel Resource Area 4 13
  - Resource Areas of Secondary Significance 13
- Bedrock Geology 14
  - Selected Bedrock Resource Area 1 14
- Summary 14

References 32

Appendix A — Suggested Additional Reading 33

Appendix B — Glossary 34

Appendix C — Geology of Sand and Gravel Deposits 36

Appendix D — Geology of Bedrock Deposits 38

Appendix E — Aggregate Quality Test Specifications 46

Conversion Factors for Measurements in Ontario Geological Survey Publications 48

Figures

1. Key Map Showing the Location of McGillivray, East Williams and West Williams Townships, Scale 1:1 800 000. v

2a-2b. Aggregate Grading Curves, McGillivray Township 26
3a-3b. Aggregate Grading Curves, East Williams Township 28
4a-4b. Aggregate Grading Curves, West Williams Township 30

Tables

Table 1. Total Sand and Gravel Resources, McGillivray, East Williams and West Williams Townships 15
Table 2. Sand and Gravel Pits, McGillivray, East Williams and West Williams Townships 16
Table 3. Selected Sand and Gravel Resource Areas, McGillivray, East Williams and West Williams Townships 19
Table 4. Total Identified Bedrock Resources, McGillivray, East Williams and West Williams Townships 20
Table 5. Quarries, McGillivray, East Williams and West Williams Townships 21
Table 6. Selected Bedrock Resource Areas, McGillivray, East Williams and West Williams Townships 21
Table 7. Summary of Test Hole Data, McGillivray, East Williams and West Williams Townships 22
Table 8. Summary of Geophysics Data, McGillivray, East Williams and West Williams Townships 24

Geological Maps (Back Pocket)

1. Distribution of Sand and Gravel Deposits, McGillivray, East Williams and West Williams Townships, Scale 1:50 000.
2. Selected Sand and Gravel Resource Areas, McGillivray, East Williams and West Williams Townships, Scale 1:50 000.
3. Bedrock Resources, McGillivray, East Williams and West Williams Townships, Scale 1:50 000.

Abstract

This report includes both an inventory and evaluation of sand and gravel, as well as bedrock resources, in McGillivray, East Williams and West Williams townships. The report is part of the Aggregate Resources Inventory Program for townships and municipalities designated under the Aggregate Resources Act.

Data analysis has resulted in the selection of four sand and gravel deposits for possible resource protection in the three townships combined in this report. The four Selected Sand and Gravel Resource Areas occupy a total of 4750 acres (1920 ha), exclusive of licenced properties. An estimated 3700 acres (1500 ha) are currently available for extraction, containing approximately 88 million tons (80 million tonnes) of granular material. The parts of the selected areas which are available for extraction represent 34% of the townships' total sand and gravel resources and 42% of the original tonnage. In addition, several deposits have been selected at the secondary level of significance. These include buried ice-contact deposits in eastern McGillivray Township, which are potential sources of high quality gravel.

Selected Sand and Gravel Resource Areas 1 and 2 are outwash deposits located in a former meltwater channel in front of the Wyoming Moraine in McGillivray Township. Total resources are approximately 3 million tons (3 million tonnes) and 8 million tons (7 million tonnes), respectively. The aggregate is of relatively high quality but the lack of crushable gravel renders the deposits suitable only for local low specification applications.

Selected Sand and Gravel Resource Area 3 is in West Williams Township. The deposit consists of ice-contact stratified drift material, which was deposited by a melting ice-margin in association with the formation of the Seaforth Moraine. The deposit contains an estimated 22 million tons (20 million tonnes) of sand and some gravel, suitable mainly for low specification road-building and other uses.

Selected Sand and Gravel Resource Area 4 includes a large beach deposit which traverses all three townships. It is located on the west flank of the Wyoming Moraine and was deposited by the waters of glacial Lake Warren. Total available resources are estimated to be 55 million tons (50 million tonnes). The material is mainly sand with thin layers of fine gravel acceptable for low specification road-building and construction uses.

The surficial deposits of the townships are underlain by limestone of the Dundee Formation and shale and limestone of the Hamilton Group. Neither of these units is suited for the production of crushed aggregate, however, shale from the Hamilton Group is suitable for drainage and structural tile manufacture. Consequently, one area overlain by thin drift has been selected in West Williams Township for bedrock resource protection. Resources in Selected Bedrock Resource Area 1 are estimated to be 58 million tons (53 million tonnes).

Selected Resource Areas are not intended to be permanent, single land use units. They represent areas in which a major resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection.

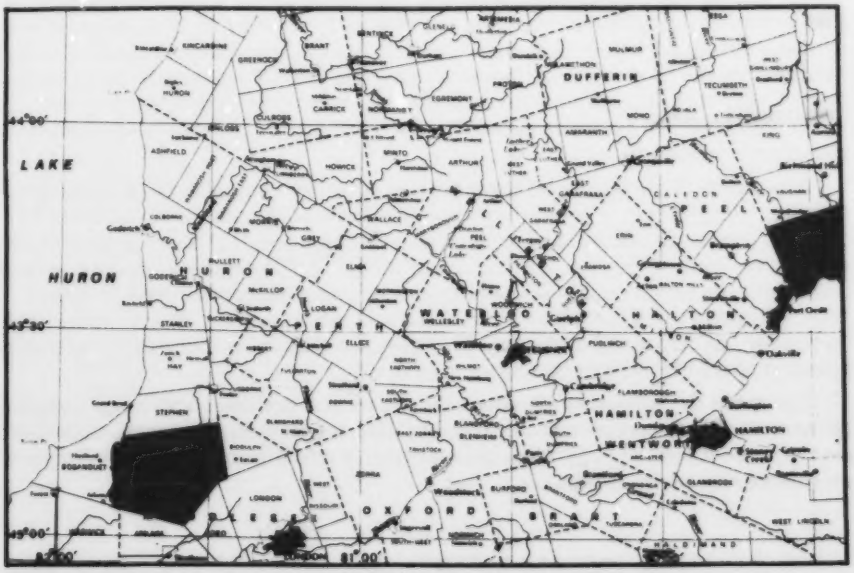

Figure 1. Key map showing the location of McGillivray, East Williams and West Williams townships, scale 1:1 800 000.

Résumé

Ce rapport comprend à la fois un inventaire et une estimation des ressources en sable et gravier ainsi que du substratum rocheux dans les cantons de McGillivray, East Williams et de West Williams. Le rapport fait partie du programme sur l'inventaire des ressources en agrégat pour les cantons et municipalités désignés sous le régime de la Loi sur les ressources en agrégat.

L'analyse de données a abouti à la sélection de quatre dépôts de sable et de gravier pour la protection possible de ressources dans les trois cantons qui sont combinés dans ce rapport. Les quatre secteurs choisis possédant des ressources en sable et gravier occupent une superficie totale de 4750 acres (1920 ha), à l'exclusion des propriétés sous licence. On estime qu'une surface de 3700 acres (1500 ha) est actuellement disponible à l'extraction avec environ 88 millions de tonnes courtes (80 millions de tonnes métriques) de matériau granulaire. Les parties des secteurs sélectionnés qui sont disponibles à l'exploitation représentent 34% des ressources totales en sable et gravier des cantons et 42% du tonnage original. Il faut aussi signaler que plusieurs dépôts ont été sélectionnés au deuxième niveau d'importance. Ceux-ci comprennent, dans la partie orientale du canton de McGillivray, des dépôts de contact glaciaire enfouis représentant des sources éventuelles en gravier de haute qualité.

Les secteurs 1 et 2 de ressources en sable et gravier sélectionnés représentent des dépôts d'épandage fluvio-glaciaire situés dans un ancien chenal d'écoulement des eaux de fonte glaciaires à l'avant de la moraine de Wyoming dans le canton de McGillivray. Les ressources totalisent environ 3 millions de tonnes courtes (3 millions de tonnes métriques) et 8 millions de tonnes courtes (7 millions de tonnes métriques) respectivement. L'agrégat est relativement de haute qualité mais le manque de gravier concassable rend les dépôts convenables seulement pour des usages locaux de basse caractéristiques.

Le secteur 3 de ressources en sable et gravier sélectionné se situe dans le canton de West Williams. Le dépôt renferme une couverture stratifiée de contact glaciaire qui s'est formée par la fonte d'une marge glaciaire en association avec la formation de la moraine de Seaforth. On estime que le dépôt contient quelques 22 millions de tonnes courtes (20 millions de tonnes) de sable et de gravier de caractéristiques inférieures convenant surtout à la construction de routes et autres usages.

Le secteur 4 de ressources en sable et gravier renferme un dépôt de plage qui passe par l'ensemble des trois cantons. Il se situe sur le flanc ouest de la moraine de Wyoming et a été déposé par les eaux du lac glaciaire Warren. Le total des ressources disponibles est estimé d'être de 55 millions de tonnes courtes (50 millions de tonnes métriques). Le matériau consiste surtout de sable avec des minces couches de gravier fin acceptable pour des usages de caractéristiques inférieures tels que le revêtement de routes et la construction.

Les dépôts de surface dans les cantons recouvrent les calcaires de la formation de Dundee et les shales et calcaires du groupe de Hamilton. Aucune de ces deux unités ne convient pour la production d'agrégat concassé, cependant, le shale du groupe de Hamilton conviendrait pour la fabrication de tuiles. En conséquent, un seul secteur possédant un recouvrement de faible épaisseur a été sélectionné dans le canton de West Williams pour la protection de ressources du substratum rocheux. Les ressources du secteur 1 de ressources du substratum rocheux sont estimées d'être de 58 millions de tonnes courtes (53 millions de tonnes métriques).

Les zones de ressources sélectionnées ne sont pas destinées à un usage unique et permanent. Elles représentent des secteurs dans lesquels une ressource importante est reconnue et peut être réservée entièrement ou partiellement pour l'exploitation et/ou comme réserve de ressources.

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Aggregate Resources Inventory of McGillivray, East Williams and West Williams Townships

Southern Ontario

By Staff[1] of the Engineering and Terrain Geology Section

1. Field work and report by I. Szoke; compilation and drafting by Staff of the Aggregate Assessment Office. Assistance with review provided by the Resident Geologist, London District of the Ministry of Northern Development and Mines. The Mineral Resources Staff of the Aylmer District Office, Ministry of Natural Resources assisted in the collection of data, field checking and review of this report.

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Introduction

Mineral aggregates, which include bedrock-derived crushed stone as well as naturally formed sand and gravel, constitute the major raw material in Ontario's road-building and construction industries. Very large amounts of these materials are used each year throughout the Province. For example, in 1987, the total tonnage of mineral aggregates extracted was 156 million tons (142 million tonnes), greater than that of any other metallic or nonmetallic commodity mined in the Province (Ontario Ministry of Northern Development and Mines 1989).

Although mineral aggregate deposits are plentiful in Ontario, they are fixed-location, nonrenewable resources which can be exploited only in those areas where they occur. Mineral aggregates are characterized by their high bulk and low unit value so that the economic value of a deposit is a function of its proximity to a market area as well as its quality and size. The potential for extractive development is usually greatest in urban fringe areas where land use competition is extreme. For these reasons the availability of adequate resources for future development is now being threatened in some areas.

Comprehensive planning and resource management strategies are required to make the best use of available resources, especially in those areas experiencing rapid development. Such strategies must be based on a sound knowledge of the total mineral aggregate resource base at both local and regional levels. The purpose of the Aggregate Resources Inventory is to provide the basic geological information required to include potential mineral aggregate resource areas in planning strategies and official plans. The reports should form the basis for discussion on those areas best suited for possible extraction. The aim is to assist decision-makers in protecting the public well-being by ensuring that adequate resources of mineral aggregate remain available for future use.

This report is a technical background document, based for the most part on geological information and interpretation. It has been designed as a component of the total planning process and should be used in conjunction with other planning considerations, to ensure the best use of a municipality's resources.

The report includes an assessment of sand and gravel resources as well as a discussion on the potential of bedrock-derived aggregate. The most recent information available has been used to prepare the report. As new information becomes available, revisions may be necessary.

Part I — Inventory Methods

FIELD AND OFFICE METHODS

The methods used to prepare the report primarily involve the interpretation of published geological data such as bedrock and surficial geology maps and reports (*see* References) as well as field examination of potential resource areas. Field methods include the examination of natural and man-made exposures of granular material. Most observations are made at quarries and sand and gravel pits located from records held by the Ontario Ministry of Transportation, the Ontario Geological Survey, and by Regional and District Offices of the Ontario Ministry of Natural Resources. Observations made at pit sites include estimates of the total face height and the proportion of gravel- and sand-sized fragments in the deposit. Observations are also made of the shape and lithology of the particles. These characteristics are important in estimating the quality and quantity of the aggregate. In areas of limited exposure, subsurface materials may be assessed by hand augering and test pitting, supplemented by test hole drilling, and geophysical surveys using hammer seismic equipment. The symbols for and locations of sample sites, test hole sites, and geophysical traverse lines are noted on Map 1.

Deposits with potential for further extractive development or those where existing data are scarce, are studied in greater detail. Representative layers in these deposits are sampled in 25- to 100-pound (11 to 45 kg) units from existing pit faces or from test pits. The samples are analysed for grain size distribution, and in some cases absorption, Los Angeles abrasion, and Magnesium Sulphate soundness tests and petrographic analyses are carried out. Analyses are performed either in the laboratories of the Soils and Aggregates Section, Engineering Materials Office, Ontario Ministry of Transportation, or in the Geoscience Laboratory, Ontario Geological Survey.

The field data are supplemented by pit information on file with the Soils and Aggregates Section of the Ontario Ministry of Transportation. Data contained in these files include field estimates of the depth, composition and "workability" of deposits, as well as laboratory analyses of the physical properties and chemical suitability of the aggregate. Information concerning the development history of the pits and acceptable uses of the aggregate is also recorded. The location, size and depth of extraction of pits licenced under the Aggregate Resources Act are obtained from records held by Regional and District Offices of the Ontario Ministry of Natural Resources. The cooperation of the above-named groups in the compilation of inventory data is gratefully acknowledged.

Aerial photographs at various scales are used to determine the continuity of deposits, especially in areas where information is limited. Water well records, held by the Ontario Ministry of the Environment, are used in some areas to corroborate deposit thickness estimates or to indicate the presence of buried granular material. These records are used in conjunction with other evidence.

Topographic maps of the National Topographic System, at a scale of 1:50 000, are used as a compilation base for the field and office data. The information is then transferred to a base map, also at a scale of 1:50 000. These base maps are prepared by the Surveys, Mapping and Remote Sensing Branch, Ontario Ministry of Natural Resources with information taken from maps of the National Topographic System by permission of Energy, Mines and Resources Canada, for presentation in the report.

RESOURCE TONNAGE CALCULATION TECHNIQUES

SAND AND GRAVEL RESOURCES

Once the interpretative boundaries of the aggregate units have been established, quantitative estimates of the possible resources available can be made. Generally, the volume of a deposit can be calculated if its areal extent and average thickness are known or can be estimated. The computation methods used are as follows. First, the area of the deposit, as outlined on the final base map, is calculated in acres. The thickness values used are an approximation of the deposit thickness, based on the face heights of pits developed in the deposit or on subsurface data such as test holes and water well logs. Original tonnage values can then be calculated by multiplying the volume of the deposit by 2500 (the density factor). This factor is approximately the number of tons in a one-foot (0.3 m) thick layer of sand and gravel, one acre (0.4 ha) in extent, assuming an average density of 110 pounds per cubic foot (1766 kg/m^3).

Tonnage = Area x Thickness x Density Factor

Tonnage calculated in this manner must be considered only as an estimate. Furthermore, such tonnages represent amounts that existed prior to any extraction of material (i.e., original tonnage) (Table 1, Column 4).

The Selected Sand and Gravel Resource Areas in Table 3 are calculated in the following way. Two successive subtractions are made from the total area. Column 3 accounts for the number of acres unavailable because of the presence of permanent cultural features and their associated setback requirements. Column 4 accounts for those areas that have previously been extracted (e.g., wayside and abandoned pits are included in this category). The remaining figure is the area of the deposit currently available for extraction (Column 5). The available area is then multiplied by the estimated deposit thickness and the density factor (Column 5 x Column 6 x 2500) to give an estimate of the sand and gravel tonnage

(Column 7) presently available for extractive development and/or resource protection.

Reserve estimates are calculated for deposits of primary significance. Reserve estimates for deposits of secondary and tertiary significance are not calculated in Table 3, however, the aggregate potential of these deposits is discussed in the report.

BEDROCK RESOURCES

The method used to calculate resources of bedrock-derived aggregate is much the same as that described above. The areal extent of bedrock formations overlain by less than 50 feet (15 m) of unconsolidated overburden is determined from bedrock geology maps, drift thickness and bedrock topography maps, and from the interpretation of water well records. The measured extent of such areas is then multiplied by the estimated quarriable thickness of the formation, based on stratigraphic analyses and on estimates of existing quarry faces in the unit. In some cases a standardized estimate of 60 feet (18 m) is used for thickness. Volume estimates are then multiplied by the density factor [the estimated weight in tons of a one-foot (0.3 m) thick section of rock, one acre (0.4 ha) in extent].

Resources of dolostone are calculated using a density factor of 165 pounds per cubic foot (2649 kg/m^3) or 3600 tons per acre (8070 t/ha). Sandstone resources are calculated using a density estimate of 146 pounds per cubic foot (2344 kg/m^3) and shale resources are calculated with a factor of 150 pounds per cubic foot (2408 kg/m^3).

UNITS AND DEFINITIONS

Although most of the measurements and other primary data available for resource tonnage calculations are given in Imperial units, Metric units have also been given in the text and on the tables which accompany the report. The Metric equivalent of the data is shown in brackets after or directly below the corresponding Imperial figures. Data are generally rounded off in accordance with the Ontario Metric Practice Guide (Metric Committee 1975).

The tonnage estimates made for sand and gravel deposits are termed possible resources (*see* Glossary, Appendix B) in accordance with terminology of the Ontario Resource Classification Scheme (Robertson 1975, p.7) and with the Association of Professional Engineers of Ontario (1976).

Part II — Data Presentation and Interpretation

Three maps, each portraying a different aspect of the aggregate resources in the municipality, accompany the report. Map 1, "Distribution of Sand and Gravel Deposits", gives a comprehensive inventory of the sand and gravel resources in the report area. Map 2, "Selected Sand and Gravel Resource Areas", shows those deposits which are considered to represent the largest and/or highest quality resources in the area. Map 3, "Bedrock Resources" shows the distribution of bedrock formations, the thickness of overlying unconsolidated sediments, and identifies the Selected Bedrock Resource Areas.

MAP 1: DISTRIBUTION OF SAND AND GRAVEL DEPOSITS

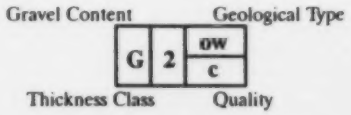
Map 1 is derived from existing surficial geology maps of the area or from aerial photograph interpretation in areas where surficial mapping is incomplete. The map shows the extent and quality of sand and gravel deposits within the study area and the present level of extractive activity.

On the map, gravel deposits are indicated by dark brown shading while sand deposits are shaded light brown. The present level of extractive activity is also indicated. Those areas which are licenced for extraction under the Aggregate Resources Act are shown by a solid outline and identified by a number which refers to the pit descriptions in Table 2. Each description notes the owner/operator, location and licenced acreage of the pit, as well as the estimated face height and percentage gravel. A number of unlicenced pits (abandoned pits or wayside pits operating on demand under authority of a permit) are identified by a numbered dot on Map 1 and described in Table 2. Similarly, test hole locations appear on Map 1 as a point symbol and are described in Table 7. Geophysics lines are shown on Map 1 by a line symbol and are interpreted in Table 8.

Map 1 also presents a summary of available information related to the quality of aggregate contained in all the known aggregate deposits in the study area. Much of this information is contained in the symbols which are found on the map. The Deposit Symbol appears for each mapped deposit and summarizes important genetic and textural data. The Texture Symbol is a circular proportional diagram which displays the grain size distribution of the aggregate in areas where bulk samples were taken.

DEPOSIT SYMBOL

The Deposit Symbol is similar to those used in soil mapping and land classification systems commonly in use in North America. The components of the symbol indicate the gravel content, thickness of material, origin (type) and quality limitations for every deposit shown on Map 1. These components are illustated by the following example:



This symbol identifies an outwash deposit 10 to 20 feet (3 to 6 m) thick containing more than 35% gravel. Excess silt and clay may limit uses of the aggregate in the deposit.

The "gravel content" and "thickness class" are basic criteria for distinguishing different deposits. The "gravel content" symbol is an upper case "S" or "G". The "S" indicates that the deposit is generally "sandy" and that gravel-sized aggregate (greater than 4.75 mm) makes up less than 35% of the whole deposit. "G" indicates that the deposit contains more than 35% gravel.

The "thickness class" indicates a depth range which is related to the potential resource tonnage for each deposit. Four thickness class divisions have been established as shown in the legend for Map 1.

Two smaller sets of letters, divided from each other by a horizontal line, follow the thickness class number. The upper series of letters identifies the geologic deposit type (the deposit types are summarized with respect to their main geologic and extractive characteristics in Appendix C) and the lower series of letters identifies the main quality limitations that may be present in the deposit as discussed in the next section.

TEXTURE SYMBOL

The Texture Symbol provides a more detailed assessment of the grain size distribution of material sampled during field study. These symbols are derived from the information plotted on the aggregate grading curves found in the report. The relative amounts of gravel, sand, and silt and clay in the sampled material are shown graphically in the Texture Symbol by the subdivision of a circle into proportional segments. The following example shows a hypothetical sample consisting of 30% gravel, 60% sand and 10% silt and clay:

MAP 2: SELECTED SAND AND GRAVEL RESOURCE AREAS

Map 2 is an interpretative map derived from an evaluation of the deposits shown on Map 1. The deposits identified on Map 2 are those which are considered to be im-

portant in ensuring an adequate resource base for the future.

All the selected sand and gravel resource areas are first delineated by geological boundaries and then classified into three levels of significance: primary, secondary and tertiary. Each area of primary significance is given a deposit number and all such deposits are shown by dark red shading on Map 2.

Selected Sand and Gravel Resource Areas of primary significance are not intended to be permanent, single land use units. They represent areas in which a major resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection.

Deposits of secondary significance are indicated by light red shading on Map 2. Such deposits are believed to contain significant amounts of sand and gravel. Although deposits of secondary significance are not considered to be the "best" resources in the report area, they may contain large quantities of sand and gravel and should be considered as part of the aggregate supply of the area.

Areas of tertiary significance are outlined on the map by a solid line but have no shading. They are not considered to be important resource areas because of their low available resources, or because of possible difficulties in extraction. Such areas may be useful for local needs but are unlikely to support large-scale development.

The process by which deposits are evaluated and selected involves the consideration of two sets of criteria. The main selection criteria are site specific, related to the characteristics of individual deposits. Factors such as deposit size, aggregate quality, and deposit location and setting are considered in the selection of those deposits best suited for extractive development. A second set of criteria involves the assessment of local aggregate resources in relation to the quality, quantity, and distribution of resources in the region in which the report area is located. The intent of such a process of evaluation is to ensure the continuing availability of sufficient resources to meet possible future demands.

SITE SPECIFIC CRITERIA

Deposit Size

Ideally, selected deposits should contain available sand and gravel resources large enough to support a commercial pit operation using a stationary or portable processing plant. In practice, much smaller deposits may be of significant value depending on the overall reserves in the rest of the municipality. Generally, deposits in Class 1 [greater than 20 feet (6 m) thick] and containing more than 35% gravel are considered to be most favourable for commercial development. Thinner deposits may be valuable in municipalities with low total resources.

Aggregate Quality

The limitations of natural aggregates for various uses result from variations in the lithology of the particles composing the deposit, and from variations in the size distribution of these particles.

Four indicators of the quality of aggregate may be included in the deposit symbols on Map 1. They are: gravel content (G or S), fines (C), oversize (O) and lithology (L).

Three of the quality indicators deal with grain size distribution. The gravel content (G or S) indicates the suitability of aggregate for various uses. Deposits containing at least 35% gravel in addition to a minimum of 20% material greater than the 26.5 mm sieve are considered to be the most favourable extractive sites, since this content is the minimum from which crushed products can be economically produced.

Excess fines (high silt and clay content) may severely limit the potential use of a deposit. Fines content in excess of 10% may impede drainage in road subbase aggregate and render it more susceptible to the effects of frost action. In asphalt aggregate, excess fines hinder the bonding of particles. Deposits known to have a high fines content are indicated by a "C" in the quality portion of the Deposit Symbol.

Deposits containing more than 20% oversize material [greater than 4 inches (10 cm) in diameter] may also have use limitations. The oversize component is unacceptable for all concrete aggregate and for road-building aggregate, so it must be either crushed or removed during processing. Deposits known to have an appreciable oversize component are indicated by an "O" in the quality portion of the Deposit Symbol.

Another indicator of the quality of an aggregate is lithology. Just as the unique physical and chemical properties of bedrock types determine their value for use as crushed rock, so do various lithologies of particles in a sand and gravel deposit determine its suitability for various uses. The presence of objectionable lithologies such as chert, siltstone and shale, even in relatively small amounts, can result in a reduction in the quality of an aggregate, especially for high quality uses such as concrete and asphalt. Similarly, highly weathered, very porous and friable rock can restrict the quality of an aggregate. Deposits known to contain objectionable lithologies are indicated by an "L" in the quality component of the Deposit Symbol.

If the Deposit Symbol shows either "C", "O", or "L" or any combination of these indicators, the quality of the deposit is considered to be reduced for some uses of the aggregate. No attempt is made to quantify the degree of limitation imposed. Assessment of the four indicators is made from published data, from data contained in files of both the Ontario Ministry of Transportation and the Engineering and Terrain Geology Section of the Ontario Geological Survey, and from field observations.

Quality data may also appear in Table 9, where the results of aggregate quality tests are listed by test type and sample location. The types of tests conducted and

the test specifications are explained in Appendixes B and E, respectively.

Analyses of unprocessed samples obtained from test holes, pits or sample sites are plotted on grain size distribution graphs. On the graphs are the Ontario Ministry of Transportation's gradation specification envelopes for aggregate products: Granular Base Course A, B and C, Hot-Laid Asphaltic Sand Nos. 1,2,3,4 and 8, and concrete sand. By plotting the gradation curves with respect to the specification envelopes, it can be determined how well the unprocessed sampled material meets the criteria for each product. These graphs, called Aggregate Grading Curves, follow the tables in the report.

Location and Setting

The location and setting of a resource area has a direct influence on its value for possible extraction. The evaluation of a deposit's setting is made on the basis of natural and man-made features which may limit or prohibit extractive development.

First, the physical context of the deposit is considered. Deposits with some physical constraint on extractive development, such as thick overburden or high water table, are less valuable resource areas because of the difficulties involved in resource recovery. Second, permanent man-made features, such as roads, railways, powerlines, and housing developments, which are built on a deposit, may prohibit its extraction. The constraining effect of legally required setbacks surrounding such features is included in the evaluation. A quantitative assessment of these constraints can be made by measurement of their areal extent directly from the topographic maps. The area rendered unavailable by these features is shown for each resource area in Table 3 (Column 3).

The assessment of sand and gravel deposits with respect to local land use and to private land ownership is an important component of the general evaluation process. These aspects of the evaluation process are not considered further in this report, but readers are encouraged to discuss them with personnel of the pertinent District Office of the Ontario Ministry of Natural Resources.

REGIONAL CONSIDERATIONS

In selecting sufficient areas for resource development, it is important to assess both the local and the regional resource base, and to forecast future production and demand patterns.

Some appreciation of future aggregate requirements in an area may be gained by assessing its present production levels and by forecasting future production trends. Such an approach is based on the assumptions that production levels in an area closely reflect the demand and that the present production "market share" of an area will remain roughly at the same level.

The aggregate resources in the region surrounding a municipality should be assessed in order to properly evaluate specific resource areas and to adopt optimum resource management plans. For example, a municipality that has large resources in comparison to its surrounding region constitutes a regionally significant resource area. Municipalities with high resources in proximity to large demand centres, such as metropolitan areas, are special cases.

Although an appreciation of the regional context is required to develop comprehensive resource management techniques, such detailed evaluation is beyond the scope of this report. The selection of resource areas made in this study is based primarily on geological data or on considerations outlined in preceding sections.

MAP 3: BEDROCK RESOURCES

Map 3 is an interpretative map derived from bedrock geology, drift thickness and bedrock topography maps, water well data from the Ontario Ministry of the Environment, oil and gas well data from the Petroleum Resources Section (Ontario Ministry of Natural Resources) and from geotechnical test hole data from various sources. Map 3 is based on concepts similar to those outlined for Maps 1 and 2, but displays both the inventory and evaluation on the one map.

The geological boundaries of the bedrock units are shown by a dashed line. Isolated outcrops are indicated by an "X". Three sets of contour lines delineate areas of less than 3 feet (1 m) of drift, areas of 3 to 25 feet (1 to 8 m) of drift, and areas of 25 to 50 feet (8 to 15 m) of drift. The extent of these areas of thin drift are shown by three shades of blue. The darkest shade indicates where bedrock outcrops or is within 3 feet (1 m) of the ground surface. These areas constitute potential resource areas because of their easy access. The medium shade indicates areas where drift cover is up to 25 feet (8 m) thick. Quarrying is possible in this depth of overburden and these zones also represent potential resource areas. The lightest shade indicates bedrock areas overlain by 25 to 50 feet (8 to 15 m) of overburden. These latter areas constitute resources which have extractive value only in specific circumstances. Outside of these delineated areas, the bedrock can be assumed to be covered by more than 50 feet (15 m) of overburden, a depth generally considered to be too great to allow economic extraction (unless part of the overburden is composed of economically attractive deposits).

Other inventory information presented on Map 3 is designed to give an indication of the present level of extractive activity in the report area. Those areas which are licenced for extraction under the Aggregate Resources Act are shown by a solid outline and identified by a number which refers to the quarry descriptions in Table 5. Each description notes the owner/operator, location, licenced acreage and an estimate of face height. Unlicenced quarries (abandoned quarries or wayside quarries operating on demand under authority of a permit) are also identified and numbered on Map 3 and de-

scribed in Table 5. Two additional symbols may appear on the map. An open dot indicates the location of a selected water well which penetrates bedrock. The overburden thickness is shown in feet beside the open dot. Similarly, test hole locations appear as a point symbol with the depth to bedrock shown in feet beside it. The test holes may be further described in Table 7.

SELECTION CRITERIA

Criteria equivalent to those used for sand and gravel deposits are used to select bedrock areas most favourable for extractive development.

The evaluation of bedrock resources is made primarily on the basis of performance and suitability data established by laboratory testing at the Ontario Ministry of Transportation. The main characteristics and uses of the bedrock units found in southern Ontario are summarized in Appendix D.

Deposit "size" is related directly to the areal extent of thin drift cover overlying favourable bedrock formations. Since vertical and lateral variations in bedrock units are much more gradual than in sand and gravel deposits, the quality and quantity of the resource are usually consistent over large areas.

Quality of the aggregate derived from specific bedrock units is established by the performance standards previously mentioned. Location and setting criteria and regional considerations are identical to those for sand and gravel deposits.

SELECTED RESOURCE AREAS

Selection of Bedrock Resource Areas has been restricted to a single level of significance. Three factors support this approach. First, quality and quantity variations are gradual. Second, the areal extent of a given quarry operation is much smaller than that of a sand and gravel pit producing an equivalent tonnage of material, and third, since crushed bedrock has a higher unit value than sand and gravel, longer haul distances can be considered. These factors allow the identification of alternative sites having similar development potential. The Selected Areas, if present, are shown on Map 3 by a line pattern and the calculated available tonnages are given in Table 6.

Selected Bedrock Resource Areas shown on Map 3 are not permanent, single land use units. They represent areas in which a major bedrock resource is known to exist and may be reserved wholly or partially for extractive development and/or resource protection.

Part III - Assessment of Aggregate Resources in McGillivray, East Williams and West Williams Townships

LOCATION AND POPULATION

The study area combines three townships: McGillivray, East Williams and West Williams. They occupy a total area of 146 617 acres (59 336 ha) in the northwest corner of Middlesex County, southwestern Ontario. These townships are shown on the Lucan (40 P/3), Parkhill (40 P/4), Grand Bend (40 P/5) and St. Marys (40 P/6) map sheets of the National Topographic System at a scale of 1:50 000.

The productive soils and generally flat relief of the land make the area well suited to agriculture. Although the land is predominantly used for farming, the farming population has decreased in recent years because of the increased size of farms and smaller families. Balancing the decreasing farm population are new rural-residential developments.

The town of Parkhill and the village of Ailsa Craig are the major local trade and retail centres. The town of Parkhill is located near the northeastern corner of West Williams Township. The village of Ailsa Craig straddles the border of McGillivray and East Williams townships. The joint population of Parkhill and Ailsa Craig reached 2207 in 1985. Figures from previous years indicate that these municipalities have experienced a low rate of growth (Ontario Ministry of Municipal Affairs and Housing 1983; Ontario Ministry of Municipal Affairs 1988). Other small unincorporated population centres within the study area include Brinsley, West McGillivray, Carlisle, Nairn and Sylvan.

Over the past ten years, the population of the study area has been relatively stable, with only a very slow rate of growth. The population, exclusive of the incorporated municipalities, increased about 1% from 3852 in 1972 to 3877 in 1985 (Ontario Ministry of Municipal Affairs and Housing 1983; Ontario Ministry of Municipal Affairs 1988). This steady trend is expected to continue with growth occurring, for the most part, in and around Parkhill (J.F. MacLaren Ltd. 1976).

Population projections for Middlesex County as a whole indicate a possible population increase up to 30% by the year 2001 (Ontario Ministry of Treasury, Economics and Intergovernmental Affairs 1976). In view of these growth estimates, the local demand for aggregate both for road building and residential construction will likely increase.

The townships are served by a network of paved and gravel-surfaced township and county roads, as well as by King's highways 4, 7 and 81. Rail access is by a line of the Canadian National Railways which passes through the town of Parkhill and the village of Ailsa Craig.

PHYSIOGRAPHY AND SURFICIAL GEOLOGY

The physiography of the townships and the distribution of unconsolidated sediments are largely the result of glacial activity, which took place during the Late Wisconsinan Substage of the Pleistocene Epoch (informally known as the "Great Ice Age"), approximately 15 000 to 12 000 years ago. Repeated advance and melting back of massive, continental ice sheets, in association with fluctuating water levels in glacial lakes and rivers, were the major contributing forces involved in creating the flat to gently rolling topography of these townships. The major physiographic regions, as discussed by Chapman and Putnam (1984), are the Horseshoe moraines and the Huron slope. The most significant physiographic feature traversing all three townships is the Wyoming Moraine. It occupies a large portion of the land surface of the municipalities east and south of Parkhill.

The oldest surface deposits in the study area are found in the southwest portion of West Williams Township, south of the Ausable River and in eastern McGillivray Township. These deposits contain ice-contact stratified drift material consisting of sand and gravel which is often capped by till. The faces of pits opened in these deposits revealed that the sand and gravel has variable texture and gravel content, with relatively little deleterious material. This variability can be attributed to the mode of deposition. The deposits were formed in close proximity to the melting ice-margin of an ice lobe centred in the Huron basin. Cooper (1979) and Sado (1980) suggest that the ice-contact sediments in West Williams Township were associated with the formation of the Seaforth Moraine during the early part of the Port Bruce Stadial about 14 000 years ago.

Stratigraphically younger surficial materials include the Rannoch, Southern (informal name) and St. Joseph tills. These tills were deposited by multiple readvances of the Huron ice lobe (Cooper 1979). Rannoch Till is the oldest surface till and is present in the eastern portion of McGillivray and East Williams townships. The material is a grey to brown, gritty to moderately stony, silt to clayey silt till. The overlying Southern and St. Joseph tills are very similar in texture and both are described in the field as grey to yellowish brown silt, silty clay or clayey silt tills with few pebbles and a moderate grit content. St. Joseph Till overlies the Southern Till and covers a substantial portion of all three townships as the surface till of the Wyoming Moraine. The absence of coarse granular material in these tills can be attributed to the predominance of shales and soft limestones in the Hamilton Group bedrock, over which the Huron lobe

advanced. The excessive fines content and lack of coarse granular material in the Rannoch, Southern and St. Joseph tills render them unsuitable for road-building and construction aggregate.

The gradual melting back of the Huron ice lobe initiated the ponding of meltwater in front of the ice sheet. The existence of glacial lakes is evidenced by glaciolacustrine plain and shoreline deposits. Glaciolacustrine wave action has also modified, and in some areas covered with granular material, the till surface and the sides of the Wyoming Moraine.

The glaciolacustrine plain deposits on both sides of the Wyoming Moraine are fine-grained sand, silt and clay. These deposits are not suited for aggregate production. However, relatively pure deposits of clay have potential for drainage and structural tile production. There is no previous history of clay extraction in McGillivray and East Williams townships. Near Parkhill in West Williams Township, however, local clay has been utilized with shale bedrock for the production of brick and tile in the past (Guillet 1967, 1977).

Shoreline deposits of glacial lakes Arkona, Whittlesey, Warren, Algonquin and Nipissing are represented by beach ridge and nearshore bar deposits of sand and gravel. The location and elevation of these deposits represent major glacial lake levels during the melting back of the Huron ice lobe, approximately 13 600 to 12 000 years ago (Cooper 1979). Aggregate found in these glaciolacustrine shoreline deposits have considerable local significance because of the general scarcity of aggregate in these townships. These relatively shallow deposits consist mostly of fine aggregate because they were derived from the fine-grained tills described above. Coarse aggregate is scarce and occurs only in limited quantities in pockets. Limited reserves, lack of crushable stone, as well as the presence of excessive amounts of deleterious lithologies and fines, limit the potential of these deposits as possible major commercial sources of aggregate.

Glaciofluvial outwash deposits containing sand and gravel are found in all three townships. The most important ones are located in McGillivray and East Williams townships in terraces along the banks of the Ausable River. During late glacial and postglacial times, surface drainage was concentrated along the course of the present day Ausable River, therefore, sand and gravel were deposited along the course of this river channel. Aggregate from these deposits in McGillivray Township tends to be coarser, slightly higher in gravel content and of better quality than aggregate from the other outwash deposits. To the south, in East Williams and West Williams townships, the outwash deposits, although larger in extent, have a much lower gravel content and increased fines content.

A large, flat-lying deposit on the bank of the Ausable River, south of Ailsa Craig, was mapped by Cooper (1979) as glaciofluvial outwash sand with minor lacustrine deltaic sand and gravel. Further investigation of this area was recommended (B.H. Feenstra, Ontario Ministry of Natural Resources, personal communication, 1981) in order to confirm the aggregate potential. Consequently, field checking, test hole drilling and geophysics work was undertaken. The results are included in Tables 7 and 8. The subsurface data indicate that fine aggregate occurs as thin layers in association with other fine-grained sediments of silt, clay and till. Test holes EW-TH-3, EW-TH-6 and EW-TH-7 indicate a decrease in granular material content to the south. The data also confirm the deltaic nature of the deposit, with the outwash material occurring towards the western portion of the deposit. Despite their shallow depth and small areal extent, outwash sand and gravel deposits are considered as significant local sources of aggregate because of the general lack of good quality sand and gravel in these townships.

The eventual draining of glacial Lake Nipissing marked the end of glacial lake occupation of McGillivray, East Williams and West Williams townships. Postglacial erosional and depositional processes have been of minor importance in modifying the physiography. The most significant recent events have been minor depositions of alluvial sediments consisting of silt, sand and gravel. Accumulation of organic matter has also occurred in several depressions.

EXTRACTIVE ACTIVITY

A total of 37 sand and gravel pits were identified and field checked, including several that were partially overgrown and currently not in use. Some shallow pits located in glaciolacustrine beach deposits have been completely depleted and returned to agricultural use. These were omitted from the inventory.

At present, 16 of the pits are licenced to operate under the Aggregate Resources Act. The licenced properties have a total area of 856.7 acres (346.7 ha) and are concentrated in ice-contact, outwash and glaciolacustrine beach deposits. Records of the total annual production from all licenced sources show that the average annual production over the eight-year period from 1981 to 1988 is 59 000 tons (54 000 tonnes).

SELECTED SAND AND GRAVEL RESOURCE AREAS

McGillivray, East Williams and West Williams townships have limited resources of sand and gravel. The nature and distribution of sand and gravel deposits are shown on Map 1. The deposits in the three townships total approximately 11 700 acres (4750 ha) and contain possible resources of 225 million tons (205 million tonnes). However, much of the material included in this estimate, especially the shallow lacustrine and outwash sand deposits, has little potential.

The sand and gravel deposits selected for possible resource protection and/or development at the primary level of significance are shown on Map 2. These include the ice-contact deposits along the southern boundary of West Williams Township, a number of outwash terrace

deposits along the banks of the Ausable River in McGillivray Township and a large beach deposit on the western flank of the Wyoming Moraine. The resource areas total approximately 4750 acres (1920 ha), exclusive of licenced properties. An estimated 3700 acres (1500 ha) are currently available for extraction and contain possible resources of 88 million tons (80 million tonnes). According to the selection criteria outlined in Part II, most of the selected deposits would normally be included at the secondary level, however, the general regional shortage of aggregate in this area and the local importance of the limited resources that are available, were considered in assigning a primary level of significance to these deposits.

Additional deposits of beach, delta, ice-contact and outwash origin have been selected at the secondary level of significance. Although these are not the "best" sources, they should be considered as part of the townships' aggregate supply.

Selected Sand and Gravel Resource Area 1

Selected Sand and Gravel Resource Area 1 is located along the Ausable River, south of Brinsley in McGillivray Township. Area 1 includes 4 small outwash terraces which were formed in the spillway channel in front of the Wyoming Moraine during the Huron ice lobe.

At the time of writing, there were 3 licenced properties (pit nos. 4, 5 and 6) in these deposits. Faces ranging from 3 to 10 feet (1 to 3 m) were observed in these pits during field checking. Pit no. 4 is the largest licenced property and exposes 6 to 10 feet (2 to 3 m) of stratified, sandy, fine to coarse gravel with a silty clayey till cap up to 5 feet (1.5 m) in thickness. A thin layer at the top of the gravel contained cemented material. This is attributed to the leaching of calcium carbonate from the overlying carbonate-rich clayey till. Similar conditions were encountered in the outwash deposit immediately south of pit no. 4. A test hole (EW-TH-1) and a geophysics traverse line (EW-GT-1) confirmed the presence of aggregate below 4.5 feet (1.4 m) of clayey surface material.

Field observations and grain size analysis of samples collected from the licenced properties indicate that the aggregate in these deposits contains 20 to 50% fine gravel and less than 20% coarse gravel (Figure 2a). The aggregate is lithologically sound and consists mainly of limestone, with some dolostone and trace amounts of Precambrian clasts. Occurrences of deleterious lithologies such as chert and shale do not pose a problem.

Quality and suitability data from the Aggregate Sources Files of the Ontario Ministry of Transportation (MTO) indicate that gravel pits in these deposits are capable of producing Hot-Laid (HL) 8 sand and stone, Granular Base Course (GBC) B and C, and pit-run gravel.

Selected Sand and Gravel Resource Area 1 totals approximately 270 acres (109 ha), exclusive of licenced properties. Cultural setback allowances and previous extraction reduce the area currently available to 150 acres (61 ha). Assuming an average deposit thickness of 8 feet (2 m), sand and gravel resources are approximately 3 million tons (3 million tonnes). Despite the good stone quality, Area 1 has a shallow depth and very limited areal extent. Consequently, the deposits are used primarily for supplying aggregate to meet some of the local demand. A high water table, as evidenced by ponding in pit no. 4, may make extraction difficult.

Selected Sand and Gravel Resource Area 2

Selected Sand and Gravel Resource Area 2 is located north of the village of Ailsa Craig, on the banks of the Ausable River in McGillivray Township. The three outwash deposits included in this area are similar in origin, material type and quality to the outwash deposits included in Area 1.

Presently, there are two unlicenced properties (pit nos. 17 and 18) in these deposits. Both of these pits and two other abandoned pits have been extensively mined in the past. Field investigation revealed a gravel content of up to 20% with no significant amounts of crushable gravel. Face heights in the pits range from 5 to 10 feet (1.5 to 3 m) exposing fine to coarse sand and fine gravel. The presence of till in the pit floors and high ground water conditions further limit the quantity and availability of remaining reserves. A test hole (EW-TH-2) near the bank of the Ausable River indicates that 6 feet (2 m) or more of unsuitable overlying material may have to be stripped from these deposits.

Aggregate suitability data obtained from MTO indicate that the aggregate is acceptable for the production of HL 8 sand, GBC B and C, and pit-run gravel. Similar to Area 1, deleterious lithologies, such as chert and shale, are not quality limitations. The major disadvantages of these deposits, however, are the lack of crushable stone and shallow depth which exclude the possibility of large-scale commercial operations.

Resource Area 2 has an unlicenced area of 540 acres (218 ha). Cultural setbacks and previous extraction reduce the presently available area to 420 acres (170 ha). Assuming an average thickness of 8 feet (2 m), sand and gravel resources are estimated to be 8 million tons (7 million tonnes).

Selected Sand and Gravel Resource Area 3

Selected Sand and Gravel Resource Area 3 is a group of 3 sandy ice-contact stratified drift deposits occupying approximately 580 acres (235 ha), exclusive of licenced properties, in the southern corner of West Williams Township. The deposits extend south into Warwick and Adelaide townships, and are believed to have formed in association with the Seaforth Moraine.

Several pits have been opened in these deposits in the past. However, at the time of writing only two properties were licenced (pit nos. 3 and 4). The rest of the pits have been depleted, turned into ponds or returned to agricultural use. Pit faces in licenced pit nos. 3 and 4 range from 10 to 25 feet (3 to 8 m) and expose poorly sorted, irregularly bedded sand and gravel with up to 35% gravel-sized material. The lithologic composition of the aggregate is largely limestone, dolostone and Precambrian clasts with 1 to 2% chert and no shale (Cooper 1979). In places, the sand and gravel deposits are covered by 2 to 4 feet (0.6 to 1.2 m) of clay and till. This overburden has to be removed before extraction of the aggregate can take place. Scarcity of crushable gravel was also noted during field visits to these deposits.

Data obtained from MTO's Aggregate Sources Files (Deike 1982), as well as grain size analysis of field samples (Figures 4a and 4b), indicate that the pits are capable of supplying GBC B and C, select subgrade and pit-run material. Petrographic analysis performed on samples taken from pit no. 4 indicates that the material is within the requirements for the production of GBC A and 16 mm crushed stone (if sufficient quantities of crushable gravel are available). The quality of coarse aggregate is poor for hot-laid asphalt and structural concrete uses (Deike 1982). Gradation characteristics of the fine aggregate (Figure 4b) indicate that it could meet gradation requirements for HL Nos. 4 and 8 asphaltic sand, as well as concrete sand with appropriate processing. The sand is usually clean, but often varies widely in gradation from fine to coarse. The presently licenced operations fall within the low to moderate pit use rating criteria of MTO. This means that these sources are capable of supplying GBC A, B and C, and select subgrade material if sufficient quantities of crushable material are available.

Selected Sand and Gravel Resource Area 3 has a total area of 440 acres (178 ha) currently available for extraction. Assuming an average thickness of usable material of 20 feet (6 m), sand and gravel resources are estimated to be 22 million tons (20 million tonnes). There is good road access and close proximity to local market areas.

Selected Sand and Gravel Resource Area 4

Selected Sand and Gravel Resource Area 4 is a glaciolacustrine beach deposit located along the western side of the Wyoming Moraine. This Area represents the shorelines of glacial Lake Warren. These shorelines were developed by fluctuating lake levels in close proximity to the ice margin, during the period of deglaciation, approximately 12 500 years ago (Cooper 1979). The Resource Area has been labelled 4a, 4b and 4c in the respective townships.

A total of 16 pits were documented. Seven pits were licenced and 9 were abandoned or wayside pits operating on demand under the authority of a permit. Field observations and samples collected and later analyzed (Figures 2a to 4b), indicate that the deposit consists of gravelly sand. The sand texture is variable throughout the deposit ranging from fine to coarse. Gravel content is estimated at 5 to 15% fine gravel and less than 5% crushable gravel, with virtually no oversize present. Interstratification of thin layers of open framework beach gravels with sand is evident in numerous pit faces. The aggregate consists mainly of limestone, dolostone and Precambrian clasts. Chert, a deleterious rock type, is also a component of the lithologic assemblage and was found to range from 6 to 19% (Cooper 1979). Overlying material is generally thin, however, the presence of groundwater at 5 to 8 feet (1.5 to 2 m) below the ground surface creates a limitation for extraction of the granular material.

Aggregate suitability data obtained from MTO indicate that the aggregate is acceptable for select subgrade, GBC B and C, hot-laid sand (with appropriate blending) and pit-run gravel applications (Deike 1982).

Resource Area 4 occupies a combined total of approximately 3350 acres (1360 ha), exclusive of licenced properties. Deletions for cultural setbacks, as well as for areas previously extracted reduce this figure to 2700 acres (1090 ha). Assuming an average deposit depth of 8 feet (2 m), available resources of sand and gravel are estimated at 55 million tons (50 million tonnes). The large size and the appreciable amount of remaining reserves make this deposit an important local source of low specification aggregate.

Resource Areas of Secondary Significance

Several buried sand and gravel deposits in eastern McGillivray Township have been selected at the secondary level of significance. These deposits have been delineated on the basis of detailed subsurface investigations conducted by Vanderveer (1989, in prep.) and Kelly and Feenstra (1991). The aggregate in these deposits is overlain by till and/or clay, which is usually less than 15 feet (5 m) thick (Kelly and Feenstra 1991). The thickness of the aggregate can range from 2 to 24 feet (0.6 to 7 m). Pit no. 9, has coarse, crushable gravel with abundant oversize particles. This is extracted from below the water table. The upper till unit is stripped off prior to extraction to avoid contamination of the underlying aggregate. Varying quantities of similar quality gravel were uncovered elsewhere in the buried deposits. Although the aggregate is of potentially high quality in these deposits, the presence of overlying till and/or clay and a variable gravel thickness may impede development. More detailed information concerning these deposits will be released at a later date (Vanderveer, in prep.).

Additional areas of glaciolacustrine beach, delta and lacustrine plain deposits, as well as glaciofluvial outwash, have been suggested for possible inclusion at the secondary level of significance. Deposit thickness and lack of crushable aggregate are the major limiting factors of these areas. The large flat-lying deposit, labelled as sand outwash-lacustrine delta and situated

between Ailsa Craig and Nairn, received particular attention because of its large size and proximity to the Ausable River meltwater channel. The excessive quantities of fine-grained sediments within this deposit require it to be ranked at the secondary level of significance.

BEDROCK GEOLOGY

Most of the study area is underlain by bedrock of the Middle Devonian Dundee Formation (Map 3). This bedrock formation consists of 60 to 160 feet (18 to 49 m) of light brown, medium-grained limestone with some chert present (Hewitt 1972). The limestone is quarried near St. Marys for the manufacture of Portland cement. Elsewhere in southwestern Ontario the formation is quarried for the production of crushed stone.

Water well data indicate that drift overlying the Dundee Formation is generally in excess of 100 feet (30 m). An exception is a small area near the Hamilton Group/Dundee Formation contact along the banks of the Ausable River in West Williams Township where drift thickness is less than 25 feet (8 m) (Cooper 1981b). Establishment of quarrying operations is unlikely in this area because of the very small areal extent of thin drift cover. Low resistance to abrasion, high absorption capacity and the presence of chert are quality constraints which also limit the feasibility of crushed stone production from this bedrock formation.

In the remainder of the report area, shales and limestones of the Middle Devonian Hamilton Group disconformably overlie the Dundee Formation, forming an erosional escarpment which is buried by the overlying glacial drift (Cooper 1979; Karrow 1973). The Hamilton Group is made up of six formations (Bell, Rockport Quarry, Arkona, Hungry Hollow, Widder and Ipperwash) which can reach a combined maximum thickness of 305 feet (93 m) in southwestern Ontario (Winder and Sanford 1972). In the report area, the Arkona and Hungry Hollow Formations are exposed in the Ausable River valley in the southwest corner of West Williams Township. The formations are thin, the Arkona being 15 to 20 feet (5 to 6 m) thick and the Hungry Hollow only 6 feet (2 m) thick. Areas covered by less than 25 feet (8 m) and 50 feet (15 m) have been outlined on Map 3. Shale belonging to the Arkona Formation has been quarried at Thedford in neighbouring Bosanquet Township and along the banks of the Ausable River in West Williams Township for brick and tile manufacture. One area of the Arkona Formation has been selected for possible resource protection.

Selected Bedrock Resource Area 1

Approximately 1000 acres (405 ha) of the Hamilton Group overlain by less than 25 feet (8 m) of drift, located along the banks of the Ausable River in West Williams Township, has been selected for possible bedrock resource protection. At the time of writing, there were two licenced quarries in the Resource Area. After removal of the overlying Hungry Hollow Formation, the Arkona Formation is mined to supply shale for the production of drainage tiles at Parkhill.

Bedrock Resource Area 1 occupies 990 acres (400 ha), exclusive of licenced properties. Deletions for cultural setbacks reduce the area currently available to 900 acres (365 ha). Assuming an average quarriable thickness of 20 feet (6 m), possible resources are approximately 58 million tons (53 million tonnes).

SUMMARY

McGillivray, East Williams and West Williams townships have limited resources of high quality sand and gravel. Four resource areas have been selected at the primary level for protection and/or development. These resource areas are capable of meeting local demand for low specification aggregate. Approximately 3700 acres (1500 ha) are currently available, with possible resources of 88 million tons (80 million tonnes). High quality gravel is potentially available from several ice-contact deposits selected at the secondary level in eastern McGillivray Township. This aggregate varies greatly in thickness and is buried beneath till and/or clay. The other secondary deposits in the township contain virtually the same type of material as the Primary Resource Areas, but have less available.

Bedrock resources underlying these townships are not well suited for the production of aggregate. However, shale from the Arkona Formation of the Hamilton Group is suitable for tile manufacture. Possible shale resources are estimated at 58 million tons (53 million tonnes).

Enquiries regarding the Aggregate Resources Inventory of McGillivray, East Williams and West Williams Townships should be directed to the Aggregate Assessment Office, Ontario Geological Survey, Ontario Ministry of Northern Development and Mines, 7th Floor, 77 Grenville Street, Toronto, Ontario, M7A 1W4, [Tel. (416) 965-1663], or to the Resident Geologist, London District, Ontario Ministry of Northern Development and Mines, P.O. Box 5463, 659 Exeter Road, London, Ontario, N6A 4L6, [Tel. (519) 661-2773] or to the Aylmer District Office, Ontario Ministry of Natural Resources, 353 Talbot Street West, Aylmer, Ontario, N5H 2S8, [Tel. (519) 773-9241].

TABLE 1. TOTAL SAND AND GRAVEL RESOURCES, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.*

1 CLASS NO.	2 DEPOSIT TYPE (*see* Appendix C)	3 AREAL EXTENT Acres (Hectares)	4 ORIGINAL TONNAGE Millions of Tons (Tonnes)
McGillivray Township			
2	G–IC	205 (83)	7 (6)
3	G–IC	520 (210)	9 (8)
	G–OW	360 (146)	7 (6)
	S–LB	2550 (1030)	51 (46)
	S–OW	540 (218)	11 (10)
4	G–OW	230 (93)	2 (2)
	S–AL	420 (170)	4 (4)
	S–LB	255 (103)	3 (3)
	S–OW	320 (130)	3 (3)
		5400 (2190)	97 (88)
East Williams Township			
3	S–LB	790 (320)	16 (14)
	S–OW	180 (73)	4 (4)
	S–OW–LD	1660 (670)	33 (30)
	S–OW–LP	400 (162)	8 (7)
4	S–LB	350 (142)	4 (4)
	S–OW	800 (325)	8 (7)
		4200 (1700)	73 (66)
West Williams Township			
1	S–IC	680 (275)	34 (31)
3	S–LB	385 (156)	8 (7)
	S–OW	270 (109)	5 (4)
4	S–AL	215 (87)	2 (2)
	S–OW	590 (239)	6 (5)
		2140 (870)	55 (50)
TOTAL FOR STUDY AREA:		11 700 (4750)	225 (205)

N.B. Minor variations in the tables are caused by rounding of data.

* *Identified deposit areas located within the town of Parkhill and village of Ailsa Craig are omitted from all tables.*

TABLE 2. SAND AND GRAVEL PITS, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREAS Acres (Hectares)	7 FACE HEIGHT Feet (Metres)	8 % GRAVEL
McGillivray Township							
LICENCED PITS							
1	-	Jacob Lagerwerf	Pt.3	19	14.8 (6.0)	4 (1.2)	0–20
2	-	Corp. of Twp. of McGillivray	12	19	25.0 (10.1)	6–10 (2–3)	0–20
3	-	Ronald L. Mawson	13	19	64.0 (25.9)	6–10 (2–3)	0–20
4	-	C.P. Corbett	Pt.17, 18,19,20	10	136.0 (55.0)	6–10 (2–3)	20–50
5	-	Donald Scott	Pt.20, 21,22	10	81.5 (33.0)	3 (1)	20–50
6	-	Lawrence E. Amos	Pt.22	9	72.4 (29.3)	3 (1)	20–50
7	-	E. Terrance Finch	Pt.23	4	52.4 (21.2)	3–6 (1–2)	0–10
8	-	James A. Scott	Pt.25, 26	1	96.4 (39.0)	5–8 (1.5–2)	0–10
9	-	Corp. of Twp. of McGillivray	Pt.33	2ECR	25.2 (10.2)	15–20 (5–6)	60–80
					567.7 (229.7)		
UNLICENCED PITS*							
10	P04–114	Mike Ryan	28	NB	-	6–10 (2–3)	0–10
11	P04–015	Martin J. Larkin	S1/2 3	19	-	6–10 (2–3)	0–10
12	P04–040	Don Dietrich	4	19	-	6–10 (2–3)	0–10
13	-	John Blancher	4	19	-	6–10 (2–3)	0–10
14	P04–087	Roy Mawson	5	19	-	6–10 (2–3)	0–10
15	P04–088	Doug Mawson	5	19	-	6–10 (2–3)	0–10
16	-	Ausable Bayfield Conservation Authority	11	19	-	5–10 (1.5–3)	0–10
17	P04–003	Lawrence Craven	28	5ECR	-	5–10 (1.5–3)	0–10
18	-	Clarence Carter	Pt.W1/2 28	5ECR	-	5–10 (1.5–3)	0–20

TABLE 2. SAND AND GRAVEL PITS, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREAS Acres (Hectares)	7 FACE HEIGHT Feet (Metres)	8 % GRAVEL
East Williams Township							
LICENCED PITS							
1	–	Joseph Masschelein	Pt.17, 18	ECR	55.6 (22.5)	3–6 (1–2)	0–10
2	–	Andrew Kustermans	Pt.16 18	ECR	7.3 (2.9)	< 5 (< 1.5)	0–20
					62.9 (25.4)		
UNLICENCED PITS*							
3	–	Ausable Bayfield Conservation Authority	3	20	–	3–6 (1–2)	0–10
4	L07–072	Shapley Siddall	30	1	–	10–20 (3–6)	20–40 variable
5	P04–104	A. Kustermans	17	ECR	–	3–6 (1–2)	0–10
6	–	D. Gillies	21	17	–	–	overgrown
7	P04–007	Ken Crawford	29	17	–	4–6 (1.2–2)	0–10
8	P04–075	J. Eedly	19	4	–	4–6 (1.2–2)	partially backfilled
9	–	H. Twinstra	18	4	–	4–8 (1.2–2)	0–10 nearly depleted
10	–	Domnic Monopoly	9	2	–	4–6 (1.2–2)	0–10
11	–	Susan McKay	9	2	–	4–6 (1.2–2)	0–10
12	–	Ron Daniel	9	2	–	4–6 (1.2–2)	0–10
13	–	J. Moore	8	2	–	4–6 (1.2–2)	0–10
West Williams Township							
LICENCED PITS							
1	–	Joseph L. Kennes	Pt.15	WCR	100.0 (40.5)	4–6 (1.2–2)	0–10
2	–	McCann Redi-Mix Inc.	Pt.4	14	50.0 (20.2)	6–10 (2–3)	0–10
3	–	Corp. of Twp. of West Williams	Pt.21	7	13.3 (5.4)	15–20 (5–6)	5–30
4	–	Grant Herrington	Pt.17, 18	7	62.8 (25.4)	10–25 (3–8)	10–35
					226.1 (91.5)		

TABLE 2. SAND AND GRAVEL PITS, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREAS Acres (Hectares)	7 FACE HEIGHT Feet (Metres)	8 % GRAVEL
UNLICENCED PITS*							
5	P04–081	K. Vernon	18	BF	–	4–6 (1.2–2)	0–10
6	P04–118	Don Waters	16	WCR	–	5–10 (1.5–3)	0–10

** Abandoned pits or wayside pits operating on demand under authority of a permit.*

TABLE 3. SELECTED SAND AND GRAVEL RESOURCE AREAS, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

1 DEPOSIT NO.	2 UNLICENCED AREA Acres (Hectares)	3 CULTURAL SETBACKS Acres (Hectares)	4 EXTRACTED AREA Acres (Hectares)	5 AVAILABLE AREA Acres (Hectares)	6 ESTIMATED DEPOSIT THICKNESS Feet (Metres)	7 AVAILABLE AGGREGATE Millions of Tons (Tonnes)
McGillivray Township						
1	270 (109)	70 (28)	50 (20)	150 (61)	8 (2)	3 (3)
2	540 (218)	70 (28)	50 (20)	420 (170)	8 (2)	8 (7)
4a	2450 (990)	470 (190)	50 (20)	1930 (780)	8 (2)	39 (35)
	3250 (1320)	610 (247)	150 (61)	2500 (1010)		50 (45)
East Williams Township						
4b	700 (285)	105 (42)	5 (2)	590 (239)	8 (2)	12 (11)
West Williams Township						
3	580 (235)	130 (53)	10 (4)	440 (178)	20 (6)	22 (20)
4c	220 (89)	35 (14)	5 (2)	180 (73)	8 (2)	4 (4)
	800 (325)	165 (67)	15 (6)	620 (250)		26 (24)
TOTAL FOR STUDY AREA:	4750 (1920)	880 (355)	170 (69)	3700 (1500)		88 (80)

TABLE 4. TOTAL IDENTIFIED BEDROCK RESOURCES, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

1 DRIFT THICKNESS Feet (Metres)	2 FORMATION	3 ESTIMATED DEPOSIT THICKNESS Feet (Metres)	4 AREAL EXTENT Acres (Hectares)	5 ORIGINAL TONNAGE Millions of Tons (Tonnes)
McGillivray Township				
		-NONE-		
East Williams Township				
		-NONE-		
West Williams Township				
0-25 (0-8)	Hamilton Group (Arkona and Hungry Hollow Formations)	20 (6)	1000 (405)	64 (58)
25-50 (8-15)	Hamilton Group (Arkona and Hungry Hollow Formations)	20 (6)	2000 (810)	128 (116)
			3000 (1210)	192 (174)
0-25 (0-8)	Dundee	60 (18)	70 (28)	15 (14)
25-50 (8-15)	Dundee	60 (18)	80 (32)	17 (15)
			150 (61)	32 (29)
TOTAL FOR STUDY AREA:			3150 (1270)	224 (203)

TABLE 5. QUARRIES, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

1 NO.	2 MTO NO.	3 OWNER/ OPERATOR	4 LOT	5 CONC.	6 LICENCED AREA Acres (Hectares)	7 FACE HEIGHT Feet (Metres)
McGillivray Township						
			-NONE-			
East Williams Township						
			-NONE-			
West Williams Township						
LICENCED QUARRIES						
1	-	Martin Clay Products	Pt.S1/2 22,23	9	12.1 (4.9)	15-20 (5-6)
2	-	Martin Clay Products	Pt.S1/2 22	9	4.1 (1.7)	15-20 (5-6)
					16.2 (6.6)	
UNLICENCED QUARRIES						
3	-	A. Atchison	Pt.23	7	-	15-20 (5-6)

TABLE 6. SELECTED BEDROCK RESOURCE AREAS, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

1 DEPOSIT NO.	2 DEPTH OF OVERBURDEN Feet (Metres)	3 UNLICENCED AREA Acres (Hectares)	4 CULTURAL SETBACKS Acres (Hectares)	5 EXTRACTED AREA Acres (Hectares)	6 AVAILABLE AREA Acres (Hectares)	7 ESTIMATED WORKABLE THICKNESS Feet (Metres)	8 AVAILABLE RESOURCES Millions of Tons (Tonnes)
1	0-25 (0-8)	990 (400)	90 (36)	2 (1)	900 (365)	20 (6)	58 (53)

TABLE 7. SUMMARY OF TEST HOLE DATA, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

Test Hole Number: EW–TH–1

Location: McGillivray Township, Lot 21, Concession 10

Elevation: Approximately 750 feet (229 m) asl

Date: October 25, 1982

Depth feet (metres)	Description
0–1 (0–0.3)	black, organic topsoil
1–4.5 (0.3–1.4)	moist, buff clay
4.5–5.5 (1.4–1.7)	wet, silty medium to coarse sand
5.5–6.5 (1.7–2.0)	wet, dirty fine to medium sand and gravel
	refusal at 6.5 feet (2.0 m) on boulder or cemented layer of sand and gravel

Test Hole Number: EW–TH–2

Location: McGillivray Township, Lot 25, Concession 6

Elevation: Approximately 750 feet (229 m) asl

Date: October 25, 1982

Depth feet (metres)	Description
0–1 (0–0.3)	black, organic topsoil
1–2 (0.3–0.6)	wet, buff sandy silt
2–5 (0.6–1.5)	wet, bluish grey clayey silt
5–6 (1.5–1.8)	moist, buff clayey silt
	end of hole at 6 feet (1.8 m)

Test Hole Number: EW–TH–3

Location: East Williams Township, Lot 25, Concession 19

Elevation: Approximately 750 feet (229 m) asl

Date: October 25, 1982

Depth feet (metres)	Description
0–1 (0–0.3)	dark, loamy topsoil
1–3 (0.3–1)	buff sandy silt
3–4 (1–1.2)	dirty fine to coarse sand and fine gravel (subrounded stones)
4–5 (1.2–1.5)	bluish grey silty clay
	end of hole at 5 feet (1.5 m)

Test Hole Number: EW–TH–4

Location: East Williams Township, Lot 29, Concession 1

Elevation: Approximately 825 feet (252 m) asl

Date: November 1, 1982

Depth feet (metres)	Description
0–12 (0–3.7)	buff clayey silt till very difficult augering because of consolidated occasionally stony material
	auger refusal at 12 feet (4 m) on boulder or cemented layer of sand and gravel

Test Hole Number: EW–TH–5

Location: East Williams Township, Lot 25, Concession 19

Elevation: Approximately 750 feet (229 m) asl

Date: November 1, 1982

Depth feet (metres)	Description
0–1 (0–0.3)	dark, loamy topsoil
1–3 (0.3–1)	dirty, wet, sandy gravel
3–10 (1–3)	buff, wet, fine silt and sand
	end of hole at 10 feet (3 m)

Test Hole Number: EW–TH–6

Location: East Williams Township, Lot 26, Concession 17

Elevation: Approximately 750 feet (229 m) asl

Date: October 25, 1982

Depth feet (metres)	Description
0–1 (0–0.3)	loamy topsoil
1–2 (0.3–0.6)	buff, dirty, sandy silt
2–3 (0.6–1)	wet, buff silty sand
3–7 (1–2.1)	moist, blue–grey silty clay
	end of hole at 7 feet (2.1 m)

TABLE 7. SUMMARY OF TEST HOLE DATA, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

Test Hole Number: EW–TH–7

Location: East Williams Township, Lot 25, Concession 17

Elevation: Approximately 750 feet (229 m) asl

Date: November 2, 1982

Depth feet (metres)	Description
0–1 (0–0.3)	dark, loamy topsoil
1–2 (0.3–0.6)	buff, silty clay
2–10 (0.6–3)	buff to grey, moist silty clay till
	end of hole at 10 feet (3 m)

Test Hole Number: EW–TH–8

Location: East Williams Township, Lot 12, Concession 5

Elevation: Approximately 725 feet (221 m) asl

Date: November 1, 1982

Depth feet (metres)	Description
0–1 (0–0.3)	loamy topsoil
1–10 (0.3–3)	fine to medium sand becoming silty and wet at 5 feet (1.5 m)
10–12 (3–3.7)	moist, bluish–grey clay
	end of hole at 12 feet (3.7 m)

Test Hole Number: EW–TH–9

Location: East Williams Township, Lot 10, Concession 2

Elevation: Approximately 760 feet (232 m) asl

Date: October 25, 1982

Depth feet (metres)	Description
0–1 (0–0.3)	dark, loamy topsoil
1–3 (0.3–1)	buff, wet silty clay
3–7 (1–2.1)	dirty, fine to medium sand and gravel (rounded stones) hole caved below 3 feet (1 m)
	end of hole at 7 feet (2.1 m)

TABLE 8. SUMMARY OF GEOPHYSICS DATA, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

Line Number: EW-GT-1

Line Direction: North to South

Method: Hammer Seismic

Location: McGillivray Township, Lot 21, Concession 10

Elevation: Approximately 750 feet (229 m) asl

Seismic Data:
Number of Layers: 3
Layer Velocities: V_1 = 1200 ft/sec (365 m/s)
V_2 = 5800 ft/sec (1770 m/s)
V_3 = 8000 ft/sec (2440 m/s)
Layer Thickness: D_1 = 8 feet (2 m)
D_2 = 11 feet (3 m) (assumed minimum)

Interpretation: Layer 1: 8 feet (2 m) of sandy, clayey silt
Layer 2: 11 feet (3 m) of cemented sand and gravel (confirmed by EW-TH-1)

Line Number: EW-GT-2

Line Direction: West to East

Method: Hammer Seismic

Location: East Williams Township, Lot 30, Concession 2

Elevation: Approximately 825 feet (250 m) asl

Seismic Data:
Number of Layers: 3
Layer Velocities: V_1 = 1200 ft/sec (365 m/s)
V_2 = 5000 ft/sec (1520 m/s)
V_3 = 10,000 ft/sec (3050 m/s)
Layer Thickness: D_1 = 6 feet (2 m)
D_2 = 22 feet (7 m)

Interpretation: Layer 1: Approximately 6 feet (2 m) of silty, sandy material (ablation till)
Layer 2: Approximately 22 feet (7 m) of sand and gravel capped by a cemented layer of consolidated material, till (pit no. 3 indicates sand and gravel)

Line Number: EW-GT-3

Line Direction: West to East

Method: Hammer Seismic

Location: East Williams Township, Lot 26, Concession 18

Elevation: Approximately 750 feet (229 m) asl

Seismic Data:
Number of Layers: 2
Layer Velocities: V_1 = 1300 ft/sec (400 m/s)
V_2 = 6700 ft/sec (2040 m/s)
Layer Thickness: D_1 = 8 feet (2 m)
D_2 = 30 feet (9 m) (assumed minimum)

Interpretation: Layer 1: Approximately 8 feet (2 m) of silty sand
Layer 2: Consolidated material, till or clay

Line Number: EW-GT-4

Line Direction: West to East

Method: Hammer Seismic

Location: East Williams Township, Lot 29, Concession 19

Elevation: Approximately 775 feet (236 m) asl

Seismic Data:
Number of Layers: 2
Layer Velocities: V_1 = 1200 ft/sec (365 m/s)
V_2 = 9700 ft/sec (2950 m/s)
Layer Thickness: D_1 = 11 feet (3 m)
D_2 = 30 feet (9 m) (assumed minimum)

Interpretation: Layer 1: Approximately 11 feet (3 m) of silty sand
Layer 2: Consolidated material, till or clay

Line Number: EW-GT-5

Line Direction: Northeast to Southwest

Method: Hammer Seismic

Location: East Williams Township, Lots 12 and 13, Concession 5

Elevation: Approximately 725 feet (221 m) asl

Seismic Data:
Number of Layers: 3
Layer Velocities: V_1 = 1250 ft/sec (380 m/s)
V_2 = 4550 ft/sec (1390 m/s)
V_3 = 5800 ft/sec (1770 m/s)
Layer Thickness: D_1 = 4.5 feet (1.4 m)
D_2 = 5.5 feet (1.7 m)

Interpretation: Layer 1: Approximately 5 feet (1.5 m) dry sand
Layer 2: Approximately 5 feet (1.5 m) wet silty sand
Layer 3: Clay (confirmed by drilling)

Line Number: EW-GT-6

Line Direction: Northeast to Southwest

Method: Hammer Seismic

Location: East Williams Township, Lot 10, Concession 3

Elevation: Approximately 760 feet (232 m) asl

Seismic Data:
Number of Layers: 2
Layer Velocities: V_1 = 1200 ft/sec (365 m/s)
V_2 = 4900 ft/sec (1490 m/s)
Layer Thickness: D_1 = 9 feet (3 m)
D_2 = 30 feet (9 m) (assumed minimum)

Interpretation: Layer 1: Approximately 9 feet (3 m) of sand and gravel
Layer 2: Approximately 30 feet (9 m) consolidated material, till

TABLE 8. SUMMARY OF GEOPHYSICS DATA, McGILLIVRAY, EAST WILLIAMS AND WEST WILLIAMS TOWNSHIPS.

Line Number: EW-GT-7

Line Direction: Northeast to Southwest

Method: Hammer Seismic

Location: East Williams Township, Lot 5, Concession 3

Elevation: Approximately 760 feet (232 m) asl

Seismic Data:
Number of Layers: 2
Layer Velocities: V_1 = 1110 ft/sec (340 m/s)
V_2 = 5600 ft/sec (1710 m/s)
Layer Thickness: D_1 = 9 feet (3 m)
D_2 = 30 feet (9 m) (assumed minimum)

Interpretation: Layer 1: Approximately 9 feet (3 m) of sand and gravel
Layer 2: Approximately 30 feet (9 m) consolidated material, till

Line Number: EW-GT-8

Line Direction: Northeast to Southwest

Method: Hammer Seismic

Location: East Williams Township, Lot 5, Concession 2

Elevation: Approximately 760 feet (232 m) asl

Seismic Data:
Number of Layers: 2
Layer Velocities: V_1 = 1500 ft/sec (455 m/s)
V_2 = 5700 ft/sec (1740 m/s)
Layer Thickness: D_1 = 5 feet (1.5 m)
D_2 = 35 feet (11 m) (assumed minimum)

Interpretation: Layer 1: Approximately 5 feet (1.5 m) of sand and gravel
Layer 2: Consolidated material, till

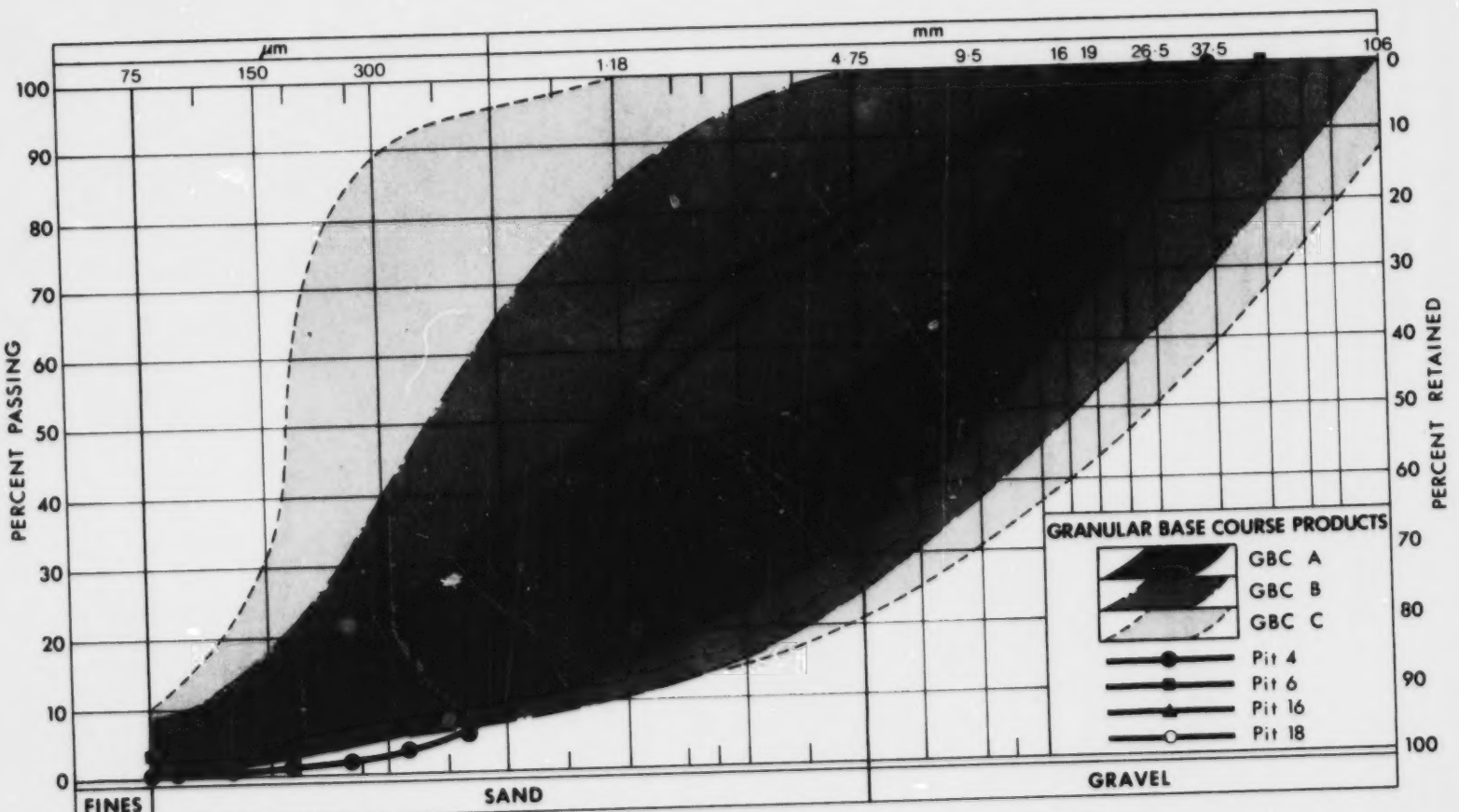


FIGURE 2a. AGGREGATE GRADING CURVES, McGILLIVRAY TOWNSHIP.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M T O Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

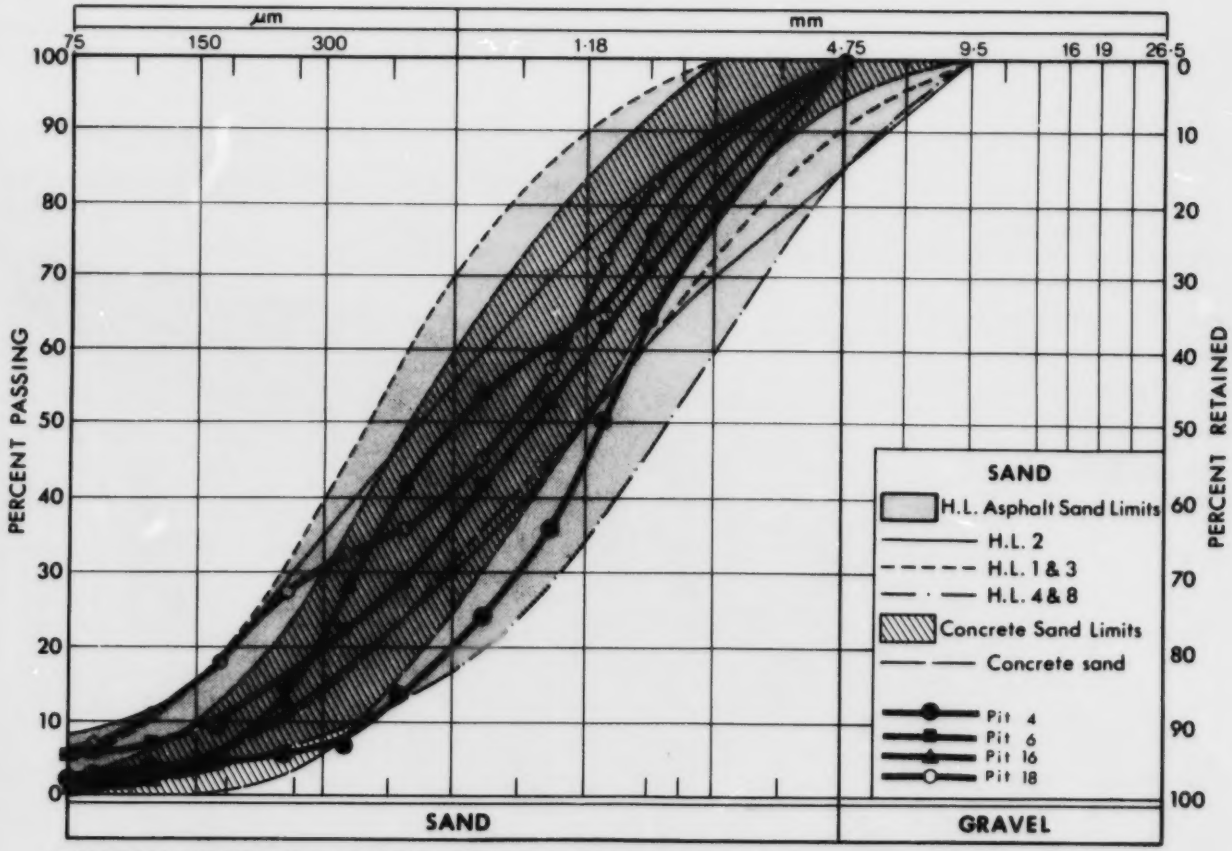


FIGURE 2b. AGGREGATE GRADING CURVES, McGILLIVRAY TOWNSHIP.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

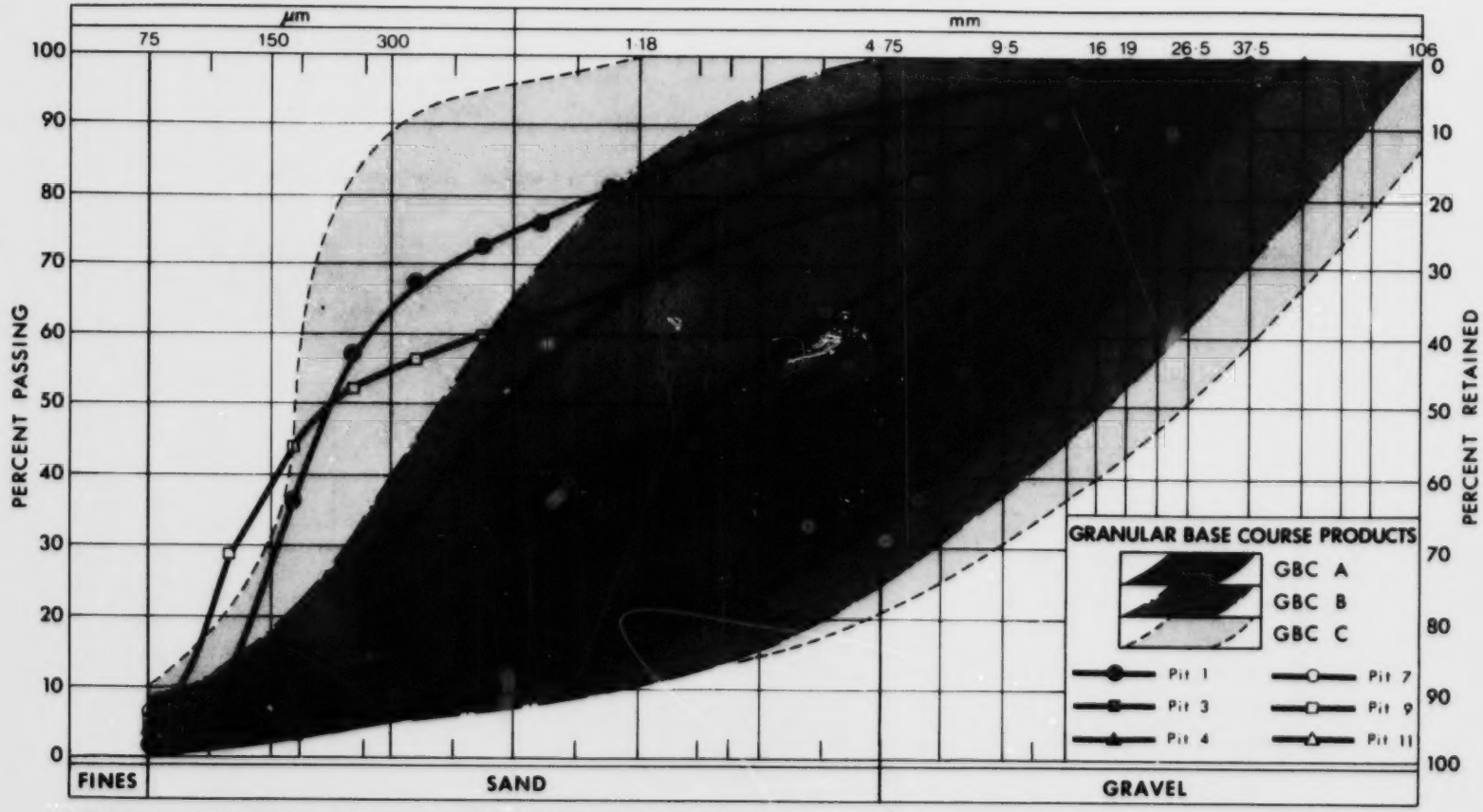


FIGURE 3a. AGGREGATE GRADING CURVES, EAST WILLIAMS TOWNSHIP.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M T O Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

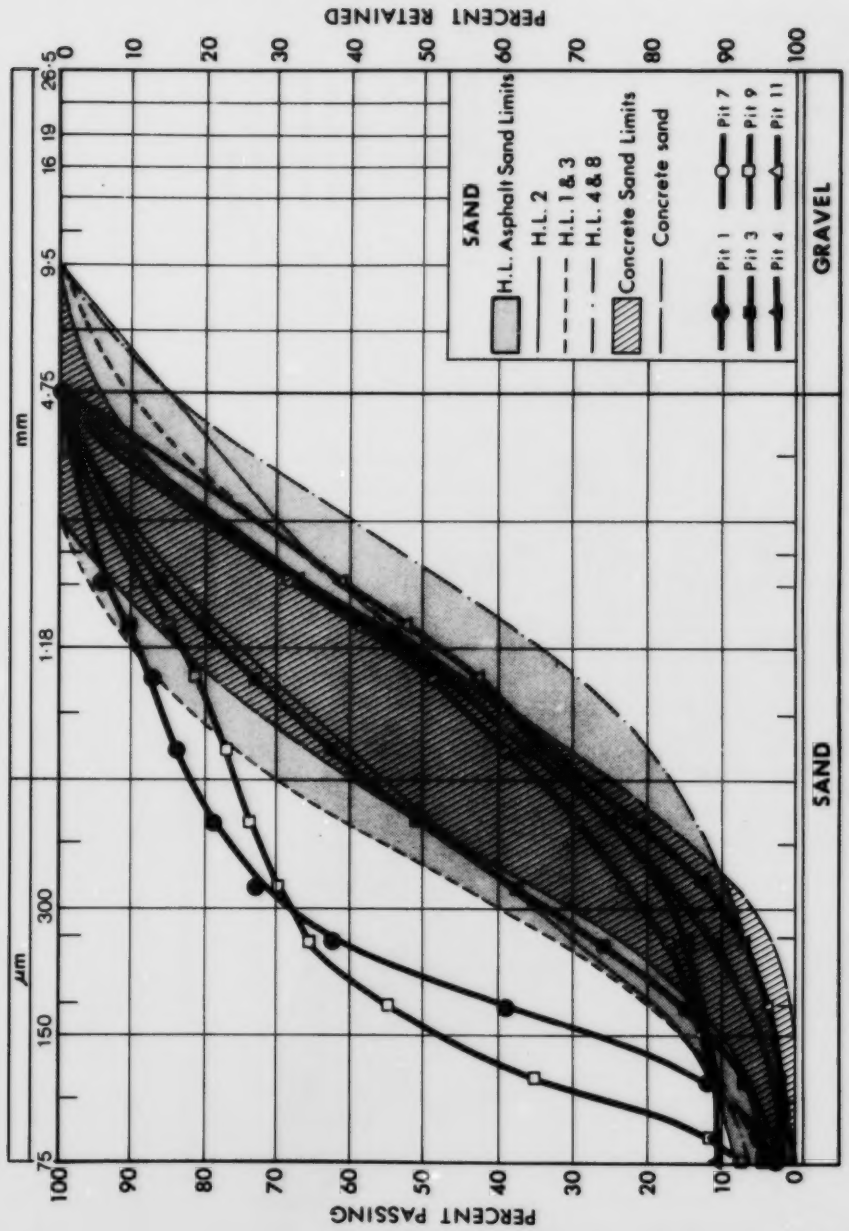


FIGURE 3b. AGGREGATE GRADING CURVES, EAST WILLIAMS TOWNSHIP.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

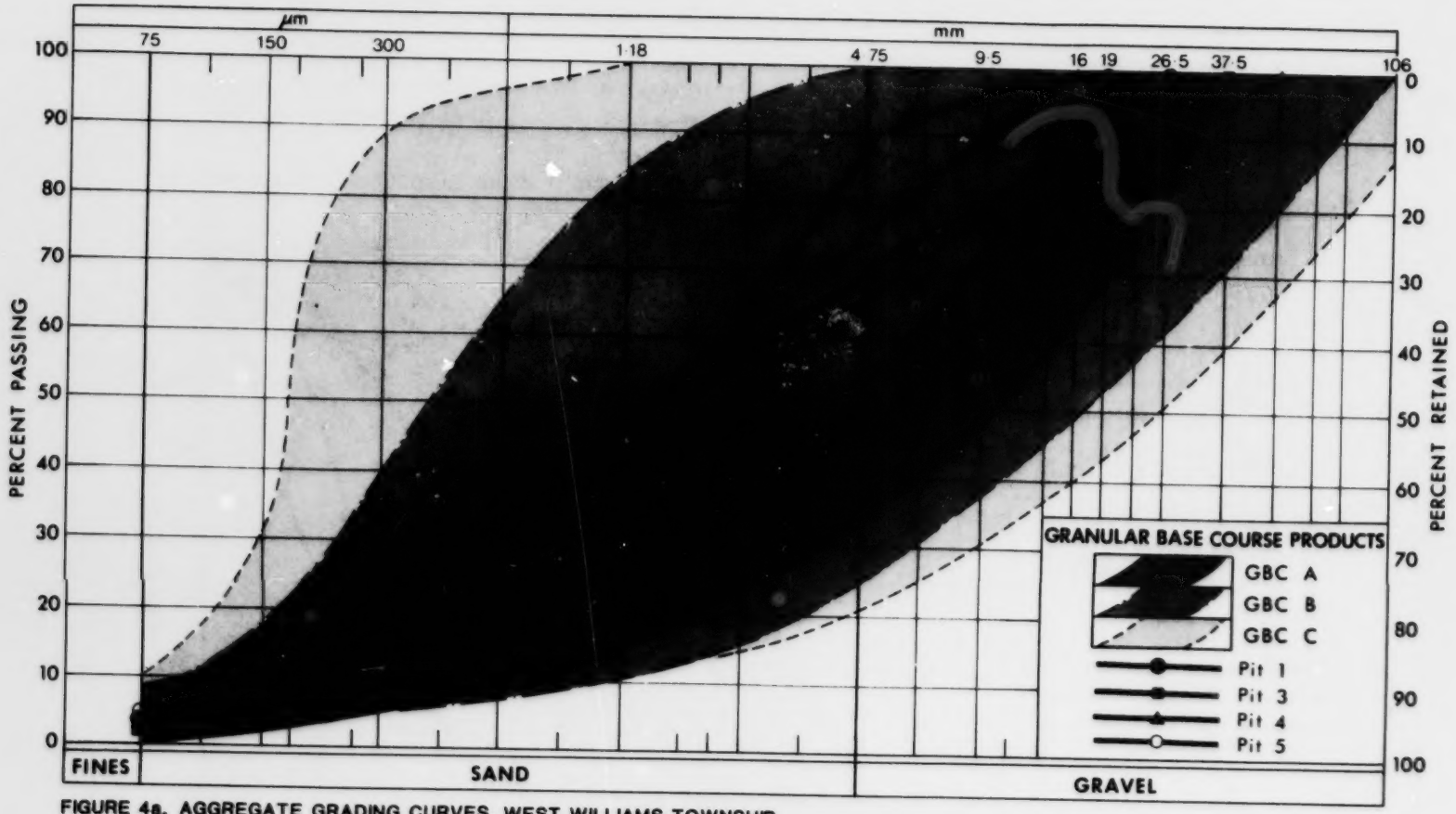


FIGURE 4a. AGGREGATE GRADING CURVES, WEST WILLIAMS TOWNSHIP.

Based on analysis of the total aggregate contained in unprocessed samples (gradation envelopes adapted from M T O Form 1010, 1980).

NOTE:

Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

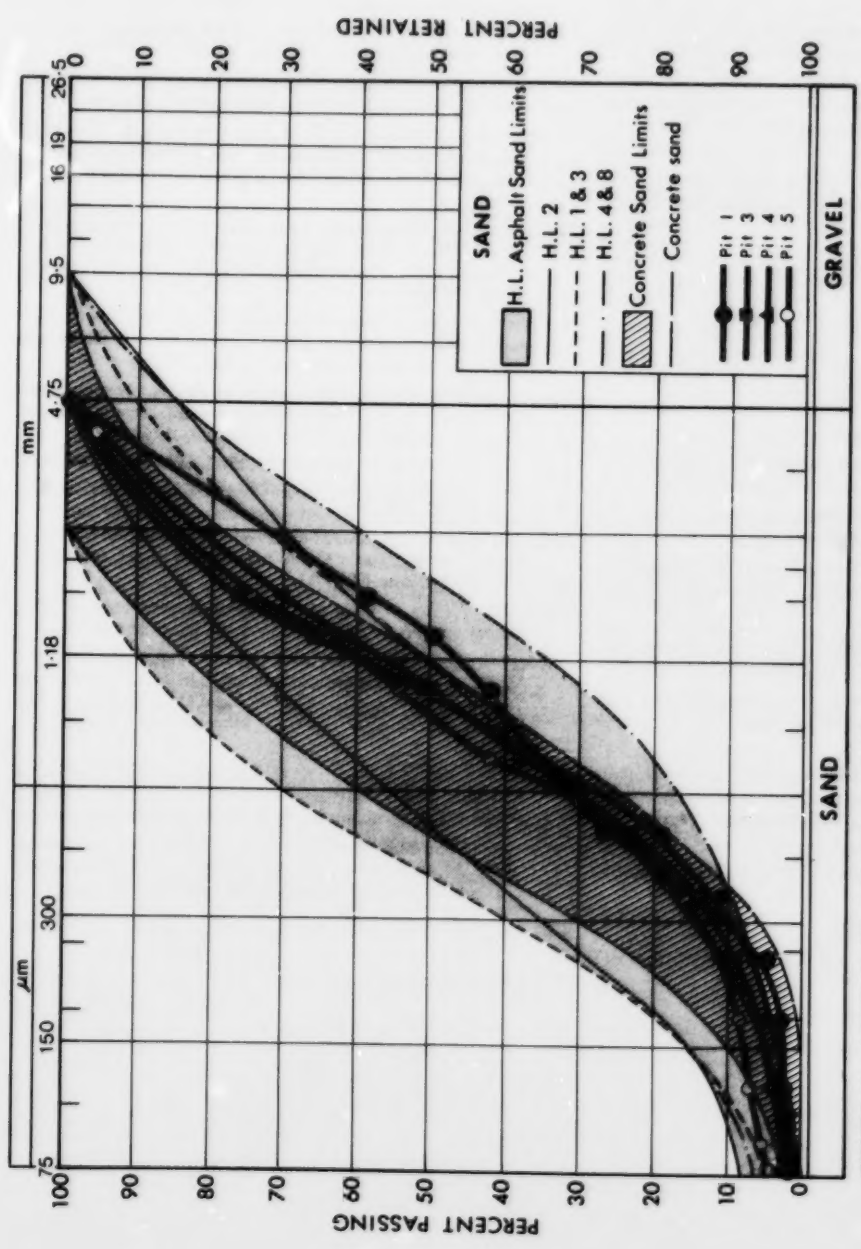


FIGURE 4b. AGGREGATE GRADING CURVES, WEST WILLIAMS TOWNSHIP.

Based on analysis of the sand fraction of the aggregate contained in unprocessed samples (gradation envelopes adapted from M.T.O. Forms 1002, 1979 and 1003, 1981).

NOTE: Information portrayed by grading curves refers strictly to a specific sample at the time of field investigation. Due to the inherent variability of sand and gravel deposits care should be exercised in extrapolating such information to the rest of the deposit.

References

Association of Professional Engineers of Ontario 1976. Performance standards for professional engineers advising on and reporting on oil, gas and mineral properties; Association of Professional Engineers of Ontario, 11p.

Chapman, L.J. and Putnam, D.F. 1984. The physiography of southern Ontario, 3rd ed.; Ontario Geological Survey, Special Volume 2, 270p.

Cooper, A.J. 1979. Quaternary geology of the Grand Bend-Parkhill area, southern Ontario; Ontario Geological Survey, Report 188, 70p.

——1981a. Drift thickness of the Grand Bend area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2451, scale 1:50 000.

——1981b. Drift thickness of the Parkhill area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2452, scale 1:50 000.

Deike, W. 1982. Aggregate suitability evaluation, townships of East and West Williams, Middlesex County; unpublished report, Aggregate Sources Research, 29p.

Hewitt, D.F. 1972. Paleozoic geology of southern Ontario; Ontario Division of Mines, Geological Report 105, 18p.

Guillet, G.R. 1967. The clay products industry of Ontario; Ontario Department of Mines, Industrial Mineral Report 22, 206p.

——1977. Clay and shale deposits of Ontario; Ontario Geological Survey, Mineral Deposits Circular 15, 117p.

Karrow, P.F. 1973. Bedrock topography in southwestern Ontario: A progress report; Proceedings Geological Association of Canada, v. 25, p.67-77.

——1977. Quaternary geology of the St. Marys area, southern Ontario; Ontario Division of Mines, Geoscience Report 148, 59p.

Karrow, P.F. and Ferguson, A.J. 1975. Bedrock topography of the St. Marys area; Ontario Division of Mines, Preliminary Map P.266 (Revised), scale 1:50 000.

Kelly, R.I. and Feenstra, B.H. 1991. Southwestern resident geologist's district-1990; *in* Report of Activities 1990, Resident Geologists, Ontario Geological Survey, Miscellaneous Paper 152, p.317-326.

MacLaren, J.F., Ltd. 1976. Official plan for the planning area of northwest Middlesex; 32p.

Ontario 1989. Aggregate resources act, 1989; Statutes of Ontario 1989, Chapter 23, Queen's Printer for Ontario.

Ontario Interministerial Committee on National Standards and Specifications (Metric Committee) 1975. Metric practice guide, 67p.

Ontario Ministry of Municipal Affairs 1988. Municipal directory 1988; Queen's Printer for Ontario, 347p.

Ontario Ministry of Municipal Affairs and Housing 1983. Municipal directory 1983; Queen's Printer for Ontario, 241p.

Ontario Ministry of Northern Development and Mines 1989. 1988 Ontario mineral score; Ontario Ministry of Northern Development and Mines, Mineral Development and Lands Branch, 194p.

Ontario Ministry of Treasury, Economics and Intergovernmental Affairs 1976. Ontario's changing population, volume 2, directions and impact of future change 1971-2001; Regional Planning Branch, 184p.

Robertson, J.A. 1975. Mineral deposit studies, mineral potential evaluation, and regional planning in Ontario; Ontario Division of Mines, Miscellaneous Paper 61, 42p.

Sado, E.V. 1980. The Quaternary stratigraphy and history of the Lucan map area, southwestern Ontario; unpublished MSc thesis, University of Waterloo, Waterloo, Ontario, 146p.

Sado, E.V. and Jones, D. 1980. Drift thickness of the Lucan area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2359, scale 1:50 000.

Sado, E.V. and Vagners, U.J. 1975. Quaternary geology of the Lucan area, southern Ontario; Ontario Division of Mines, Preliminary Map P.1048, scale 1:50 000.

Sanford, B.V. 1969. Geology of the Toronto-Windsor area, Ontario; Geological Survey of Canada, Map 1263A, scale 1:250 000.

Vanderveer, D.G. 1989. Delineation of a buried aggregate deposit in McGillivray Township, Middlesex County, southwestern Ontario; *in* Summary of Field Work and Other Activities 1989, Ontario Geological Survey, Miscellaneous Paper 146, p.213-217.

Vanderveer, D.G. in preparation. Buried aggregate resources in the Pinehurst and Leamington areas of southwestern Ontario; Ontario Geological Survey, Open File Report.

Winder, C.G. and Sanford, B.V. 1972. Stratigraphy and paleontology of the Paleozoic rocks of southern Ontario; 24th International Geological Congress, Excursion A45-C45, 74p.

Appendix A — Suggested Additional Reading

Banerjee, I. and McDonald, B.C. 1975. Nature of esker sedimentation; *in* Glaciofluvial and Glaciolacustrine Sedimentation. Society of Economic Paleontologists and Mineralogists, Special Paper no. 23, p.132-154.

Bates, R.L. and Jackson, J.A. eds. 1987. Glossary of geology, 3rd ed.; American Geological Institute, Alexandria, 788p.

Bauer, A.M. 1970. A guide to site development and rehabilitation of pits and quarries; Ontario Department of Mines, Industrial Mineral Report 33, 62p.

Cowan, W.R. 1977. Toward the inventory of Ontario's mineral aggregates; Ontario Geological Survey, Miscellaneous Paper 73, 19p.

Fairbridge, R.W. ed. 1968. The encyclopedia of geomorphology; Encyclopedia of Earth Sciences, v.3, Reinhold Book Corp., New York, 1295p.

Flint, R.F. 1971. Glacial and Quaternary geology; John Wiley and Sons Inc., New York, 892p.

Guillet, G.R. and Joyce, I.H. 1987. The clay and shale industries of Ontario; Ontario Ministry of Natural Resources, 157p.

Derry Michener Booth and Wahl and Ontario Geological Survey 1989a. Limestone industries of Ontario, volume I – geology, properties and economics; Ontario Ministry of Natural Resources, Land Management Branch, 158p.

——1989b. Limestone industries of Ontario, volume II – limestone industries and resources of eastern and northern Ontario; Ontario Ministry of Natural Resources, Land Management Branch, 196p.

——1989c. Limestone industries of Ontario, volume III – limestone industries and resources of central and southwestern Ontario; Ontario Ministry of Natural Resources, Land Management Branch, 175p.

Hewitt, D.F. 1964a. Building stones of Ontario, part I introduction; Ontario Department of Mines, Industrial Mineral Report 14, 43p.

——1964b. Building stones of Ontario, part II limestone; Ontario Department of Mines, Industrial Mineral Report 15, 43p.

——1964c. Building stones of Ontario, part III marble; Ontario Department of Mines, Industrial Mineral Report 16, 89p.

——1964d. Building stones of Ontario, part IV sandstone; Ontario Department of Mines, Industrial Mineral Report 17, 57p.

——1972. Paleozoic geology of southern Ontario; Ontario Division of Mines, Geological Report 105, 18p.

Hewitt, D.F. and Karrow, P.F. 1963. Sand and gravel in southern Ontario; Ontario Department of Mines, Industrial Mineral Report 11, 151p.

Hewitt, D.F. and Vos, M.A. 1970. Urbanization and rehabilitation of pits and quarries; Ontario Department of Mines, Industrial Mineral Report 34, 21p.

Lowe, S.B. 1980. Trees and shrubs for the improvement and rehabilitation of pits and quarries in Ontario; Ontario Ministry of Natural Resources, 71p.

McLellan, A.G., Yundt, S.E. and Dorfman, M.L. 1979. Abandoned pits and quarries in Ontario; Ontario Geological Survey, Miscellaneous Paper 79, 36p.

Michalski, M.F.P., Gregory, D.R. and Usher, A.J. 1987. Rehabilitation of pits and quarries for fish and wildlife; Ontario Ministry of Natural Resources, Land Management Branch, 59p.

Ontario Mineral Aggregate Working Party 1977. A policy for mineral aggregate resource management in Ontario; Ontario Ministry of Natural Resources, 232p.

Ontario Ministry of Natural Resources 1975. Vegetation for the rehabilitation of pits and quarries; Forest Management Branch, Division of Forests, 38p.

Peat, Marwick and Partners and M.M. Dillon Limited 1981a. Mineral aggregate transportation study; Industrial Mineral Background Paper 1, 133p.

——1981b. Mineral aggregate transportation study; Industrial Mineral Background Paper 1a, 26p.

Proctor and Redfern Limited 1974. Mineral aggregate study, central Ontario planning region; prepared for the Ontario Ministry of Natural Resources, 200p.

Proctor and Redfern Limited and Gartner Lee Associates Limited 1975. Mineral aggregate study and geological inventory of part of the eastern Ontario region; prepared for the Ontario Ministry of Natural Resources, 326p.

——1977. Mineral aggregate study and geological inventory, southwestern region of Ontario; prepared for the Ontario Ministry of Natural Resources, 246p.

Rogers, C.A. 1985a. Alkali–aggregate reactions, concrete aggregate testing and problem aggregates in Ontario: a review, 5th ed.; Ontario Ministry of Transportation and Communications, Engineering Materials Office, Soils and Aggregates Section, Report EM–31, 44p.

——1985b. Evaluation of the potential for expansion and cracking due to the alkali–carbonate reaction; *in* Cement, Concrete and Aggregates, CCAGDP, v.8, no.1, p.13–23.

Appendix B — Glossary

Abrasion resistance: Tests such as the Los Angeles abrasion test are used to measure the ability of aggregate to resist crushing and pulverizing under conditions similar to those encountered in processing and use. Measuring resistance is an important component in the evaluation of the quality and prospective uses of aggregate. Hard, durable material is preferred for road building.

Absorption capacity: Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate.

Aggregate: Any hard, inert, construction material (sand, gravel, shells, slag, crushed stone or other mineral material) used for mixing in various-sized fragments with a cement or bituminous material to form concrete, mortar, etc., or used alone for road building or other construction. Synonyms include mineral aggregate and granular material.

Aggregate Abrasion Value: This test directly measures the resistance of aggregate to abrasion with silica sand and a steel disk. The higher the value, the lower the resistance to abrasion. For high quality asphalt surface course uses, values of less than 6 are desirable.

Alkali-aggregate reaction: A chemical reaction between the alkalis of Portland cement and certain minerals found in rocks used for aggregate. Alkali-aggregate reactions are undesirable because they can cause expansion and cracking of concrete. Although perfectly suitable for building stone and asphalt applications, alkali-reactive aggregates should be avoided for structural concrete uses.

Beneficiation: Beneficiation of aggregates is a process or combination of processes which improves the quality (physical properties) of a mineral aggregate and is not part of the normal processing for a particular use, such as routine crushing, screening, washing or classification. Heavy media separation, jigging, or application of special crushers (e.g., "cage mill") are usually considered processes of beneficiation.

Blending: Required in cases of extreme coarseness, fineness, or other irregularities in the gradation of unprocessed aggregate. Blending is done with approved sand-sized aggregate in order to satisfy the gradation requirements of the material.

Bulk Relative Density: An aggregate with low relative density is lighter in weight than one with a high relative density. Low relative density aggregates (less than about 2.5) are often non-durable for many aggregate uses.

Cambrian: The first period of the Paleozoic Era, thought to have covered the time between 570 and 500 million years ago. The Cambrian precedes the Ordovician Period.

Clast: An individual constituent, grain or fragment of a sediment or rock, produced by the mechanical weathering of larger rock mass. Synonyms include particle and fragment.

Crushable aggregate: Unprocessed gravel containing a minimum of 35% coarse aggregate larger than the No. 4 sieve (4.75 mm) as well as a minimum of 20% greater than the 26.5 mm sieve.

Deleterious lithology: A general term used to designate those rock types which are chemically or physically unsuited for use as construction or road-building aggregates. Such lithologies as chert, shale, siltstone and sandstone may deteriorate rapidly when exposed to traffic and other environmental conditions.

Devonian: A period of the Paleozoic Era thought to have covered the span of time between 395 and 345 million years ago, following the Silurian Period. Rocks formed in the Devonian Period are among the youngest found in Ontario.

Dolostone: A carbonate sedimentary rock consisting chiefly of the mineral dolomite and containing relatively little calcite (dolostone is also known as dolomite).

Drift: A general term for all unconsolidated rock debris transported from one place and deposited in another, distinguished from underlying bedrock. In North America, glacial activity has been the dominant mode of transport and deposition of drift. Synonyms include overburden and surficial deposit.

Drumlin: A low, smoothly rounded, elongated hill, mound, or ridge composed of glacial materials. These landforms were formed beneath an advancing ice sheet, and were shaped by its flow.

Eolian: Pertaining to the wind, especially with respect to landforms whose constituents were transported and deposited by wind activity. Sand dunes are an example of an eolian landform.

Fines: A general term used to describe the size fraction of an aggregate which passes (is finer than) the No. 200 mesh screen (0.075 mm). Also described informally as "dirt", these particles are in the silt and clay size range.

Glacial lobe: A tongue-like projection from the margin of the main mass of an ice cap or ice sheet. During the Pleistocene Epoch several lobes of the Laurentide continental ice sheet occupied the Great Lakes basins. These lobes advanced then melted back numerous times during the Pleistocene, producing the complex arrangement of glacial material and landforms found in southern Ontario.

Gradation: The proportion of material of each particle size, or the frequency distribution of the various sizes which constitute a sediment. The strength, durability, permeability and stability of an aggregate depend to a great extent on its gradation. The size limits for different particles are as follows:

Boulder	more than 200 mm
Cobbles	75-200 mm
Coarse Gravel	26.5-75 mm
Fine Gravel	4.75-26.5 mm
Coarse Sand	2-4.75 mm
Medium Sand	0.425-2 mm
Fine Sand	0.075-0.425 mm
Silt, Clay	less than 0.075 mm

Granular base course: Components of the pavement structure of a road, which are placed on the subgrade and are designed to provide strength, stability and drainage, as well as support for surfacing materials. Several types have been defined: Granular Base Course A consists of crushed and processed aggregate and has relatively stringent quality standards in comparison to Granular Base Course B and C which are usually pit-run or other unprocessed aggregate.

Hot-laid (or asphaltic) aggregate: Bituminous, cemented aggregates used in the construction of pavements either as surface or bearing course (HL 1, 3 and 4), or as binder course (HL 2 and 8) used to bind the surface course to the underlying granular base course.

Lithology: The description of rocks on the basis of such characteristics as colour, structure, mineralogic composition and grain size. Generally, the description of the physical character of a rock.

Los Angeles Abrasion and Impact test: This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported, and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium Sulphate Soundness test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible to freezing and thawing will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Meltwater channel: A drainage way, often terraced, produced by water flowing away from a melting glacier margin.

Ordovician: An early period of the Paleozoic Era thought to have covered the span of time between 500 and 435 million years ago.

Paleozoic era: One of the major divisions of the geologic time scale thought to have covered the time between 570 and 230 million years ago, the Paleozoic Era (or Ancient Life Era) is subdivided into six geologic periods, of which only four (Cambrian, Ordovician, Silurian and Devonian) can be recognized in southern Ontario.

Petrographic examination: Individual aggregate particles in a sample are divided into categories good, fair, poor, and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

Pleistocene: An epoch of the recent geological past including the time from approximately 2 million years ago to 7000 years ago. Much of the Pleistocene was characterized by extensive glacial activity and is popularly referred to as the "Great Ice Age".

Polished Stone Value: This test measures the frictional properties of aggregates after 6 hours of abrasion and polishing with an emery abasive. The higher the PSV, the higher the frictional properties of the aggregate. Values less than 45 indicate marginal frictional properties, while values greater than 55 indicate excellent frictional properties.

Possible resource: Reserve estimates based largely on broad knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on assumed continuity or repetition for which there are reasonable geological indications.

Precambrian: The earliest geological period extending from the consolidation of the earth's crust to the beginning of the Cambrian.

Shale: A fine-grained, sedimentary rock formed by the consolidation of clay, silt or mud and characterized by well developed bedding planes, along which the rock breaks readily into thin layers. The term shale is also commonly used for fissile claystone, siltstone and mudstone.

Silurian: An early period of the Palezoic Era thought to have covered the time between 435 and 395 million years ago. The Silurian follows the Ordovician Period and precedes the Devonian Period.

Soundness: The ability of the components of an aggregate to withstand the effects of various weathering processes and agents. Unsound lithologies are subject to disintegration caused by the expansion of absorbed solutions. This may seriously impair the performance of road-building and construction aggregates.

Till: Unsorted and unstratified rock debris, deposited directly by glaciers, and ranging in size from clay to large boulders.

Wisconsinan: Pertaining to the last glacial period of the Pleistocene Epoch in North America. The Wisconsinan began approximately 100 000 years ago and ended approximately 7000 years ago. The glacial deposits and landforms of southern Ontario are predominantly the result of glacial activity during the Wisconsinan Stage.

Appendix C — Geology of Sand and Gravel Deposits

The type, distribution, and extent of sand and gravel deposits in southern Ontario are the result of extensive glacial and glacially influenced activity in Wisconsinan time during the Pleistocene Epoch, approximately 100 000 to 7000 years ago. The deposit types reflect the different depositional environments that existed during the melting and retreat of the continental ice masses, and can readily be differentiated on the basis of their morphology, structure, and texture. The deposit types are described below.

GLACIOFLUVIAL DEPOSITS

These deposits can be divided into two broad categories: those that were formed in contact with (or in close proximity to) glacial ice, and those that were deposited by meltwaters carrying materials beyond the ice margin.

Ice-Contact Terraces (ICT): These are glaciofluvial features deposited between the glacial margin and a confining topographic high, such as the side of a valley. The structure of the deposits may be similar to that of outwash deposits, but in most cases the sorting and grading of the material is more variable and the bedding is discontinuous because of extensive slumping. The probability of locating large amounts of crushable aggregate is moderate, and extraction may be expensive because of the variability of the deposits both in terms of quality and grain size distribution.

Kames (K): Kames are defined as mounds of poorly sorted sand and gravel deposited by meltwater in depressions or fissures on the ice surface or at its margin. During glacial retreat, the melting of supporting ice causes collapse of the deposits, producing internal structures characterized by bedding discontinuities. The deposits consist mainly of irregularly bedded and cross-bedded, poorly sorted sand and gravel. The present forms of the deposits include single mounds, linear ridges (crevasse fillings) or complex groups of landforms. The latter are occasionally described as "undifferentiated ice-contact stratified drift" (IC) when detailed subsurface information is unavailable. Since kames commonly contain large amounts of fine-grained material and are characterized by considerable variability, there is generally a low to moderate probability of discovering large amounts of good quality, crushable aggregate. Extractive problems encountered in these deposits are mainly the excessive variability of the aggregate and the rare presence of excess fines (silt- and clay-sized particles).

Eskers (E): Eskers are narrow, sinuous ridges of sand and gravel deposited by meltwaters flowing in tunnels within or at the base of glaciers, or in channels on the ice surface. Eskers vary greatly in size. Many, though not all eskers, consist of a central core of poorly sorted and stratified gravel characterized by a wide range in grain size. The core material is often draped on its flanks by better sorted and stratified gravel. The deposits have a high probability of containing a large proportion of crushable aggregate, and since they are generally built above the surrounding ground surface, are convenient extraction sites. For these reasons esker deposits have been traditional aggregate sources throughout Ontario, and are significant components of the total resources of many areas.

Some planning constraints and opportunities are inherent in the nature of the deposits. Because of their linear nature, the deposits commonly extend across several property boundaries leading to unorganized extractive development at numerous small pits. On the other hand, because of their form, eskers can be easily and inexpensively extracted and are amenable to rehabilitation and sequential land use.

Undifferentiated Ice-Contact Stratified Drift (IC): This designation may include deposits from several ice-contact, depositional environments which usually form extensive, complex landforms. It is not feasible to identify individual areas of coarse-grained material within such deposits because of their lack of continuity and grain size variability. They are given a qualitative rating based on existing pit and other subsurface data.

Outwash (OW): Outwash deposits consist of sand and gravel laid down by meltwaters beyond the margin of the ice lobes. The deposits occur as sheets or as terraced valley fills (valley trains) and may be very large in extent and thickness. Well developed outwash deposits have good horizontal bedding and are uniform in grain size distribution. Outwash deposited near the glacier's margin is much more variable in texture and structure. The probability of locating useful crushable aggregates in outwash deposits is moderate to high depending on how much information on size, distribution and thickness is available.

Subaqueous Fan (SF): Subaqueous fans are formed within or near the mouths of meltwater conduits when sediment laden meltwaters are discharged into a standing body of water. The geometry of the resulting deposit is fan or lobe shaped. Several of these lobes may be joined together to form a larger, continuous sedimentary body. Internally, subaqueous fans consist of stratified sands and gravels which may exhibit wide variations in grain size distribution. As these features were deposited under glacial lake waters, silt and clay which settled out of these lakes may be associated in varying amounts with these deposits. The variability of the sediments and presence of fines are the main extractive problems associated with these deposits.

Alluvium (AL): Alluvium is a general term for clay, silt, sand, gravel, or similar unconsolidated material deposited during postglacial time by a stream as sorted or semi-sorted sediment, on its bed or on its floodplain. The probability of locating large amounts of crushable aggregate in alluvial deposits is low, and they have gen-

erally low value because of the presence of excess silt- and clay-sized material. There are few large postglacial alluvium deposits in Ontario.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine Beach Deposits (LB): These are relatively narrow, linear features formed by wave action at the shores of glacial lakes that existed at various times during the deglaciation of southern Ontario. Well developed lacustrine beaches are usually less than 20 feet (6 m) thick. The aggregate is well sorted and stratified and sand-sized material commonly predominates. The composition and size distribution of the deposit depends on the nature of the source material. The probability of obtaining crushable aggregate is high when the material is developed from coarse-grained materials such as a stony till, and low when developed from fine-grained materials. Beaches are relatively narrow, linear deposits, so that extractive operations are often numerous and extensive.

Glaciolacustrine Deltas (LD): These features were formed where streams or rivers of glacial meltwater flowed into lakes and deposited their suspended sediment. In southern Ontario such deposits tend to consist mainly of sand and abundant silt. However, in near-ice and ice-contact positions, coarse material may be present. Although deltaic deposits may be large, the probability of obtaining coarse material is generally low.

Glaciolacustrine Plains (LP): The nearly level surface marking the floor of an extinct glacial lake. The sediments which form the plain are predominantly fine to medium sand, silt, and clay, and were deposited in relatively deep water. Lacustrine deposits are generally of low value as aggregate sources because of their fine grain size and lack of crushable material. In some aggregate-poor areas, lacustrine deposits may constitute valuable sources of fill and some granular base course aggregate.

GLACIAL DEPOSITS

End Moraines (EM): These are belts of glacial drift deposited at, and parallel to, glacier margins. End moraines commonly consist of ice-contact stratified drift and in such instances are usually called kame moraines. Kame moraines commonly result from deposition between two glacial lobes (interlobate moraines). The probability of locating aggregates within such features is moderate to low. Exploration and development costs are high. Moraines may be very large and contain vast aggregate resources, but the location of the best areas within the moraine is usually poorly defined.

EOLIAN DEPOSITS

Windblown Deposits (WD): Windblown deposits are those formed by the transport and deposition of sand by winds. The form of the deposits ranges from extensive, thin layers to well developed linear and crescentic ridges known as dunes. Most windblown deposits in southern Ontario are derived from, and deposited on, pre-existing lacustrine sand plain deposits. Windblown sediments almost always consist of fine to coarse sand and are usually well sorted. The probabiltiy of locating crushable aggregate in windblown deposits is very low.

Appendix D — Geology of Bedrock Deposits

The purpose of this appendix is to familiarize the reader with the general bedrock geology of southern Ontario (Figure D1), and the potential uses of the various bedrock formations where known. The reader is cautioned against using this information for more specific purposes. The stratigraphic chart (Figure D2) is intended only to illustrate the stratigraphic sequences in particular geographic areas and should not be used as a regional correlation table.

The following description is arranged in ascending stratigraphic order, on a group and formation basis. Precambrian rocks are not discussed. Additional stratigraphic information is included for some formations where necessary. The publications and maps of the Ontario Geological Survey and the Geological Survey of Canada should be referred to for more detailed information. The composition, thickness, and uses of the formations are discussed. If a formation may be suitable for use as aggregate and aggregate suitability test data is available, the data has been included in the form of ranges. The following short forms have been used in presenting this data: PSV = Polished Stone Value, AAV = Aggregate Abrasion Value, $MgSO_4$ = Magnesium Sulphate Soundness Test (loss in percent), LA = Los Angeles Abrasion and Impact Test (loss in percent), Absn = Absorption (percent), BRD = Bulk Relative Density, PN (Asphalt & Concrete) = Petrographic Number for Asphalt and Concrete use.

The ranges are intended as a guide only and care should be exercised in extrapolating the information to specific situations. Aggregate suitability test data has been provided by the Ontario Ministry of Transportation.

Covey Hill Formation (Cambrian)

STRATIGRAPHY: lower formation of the Potsdam Group. COMPOSITION: interbedded non-calcareous feldspathic conglomerate and sandstone. THICKNESS: 0 to 45 feet (0 to 14 m). USES: has been quarried for aggregate in South Burgess Township, Leeds County.

Nepean Formation (Cambro-Ordovician)

STRATIGRAPHY: upper formation of the Potsdam Group. COMPOSITION: thin-bedded to massive quartz sandstone with some conglomerate interbeds and rare shaly partings. THICKNESS: 0 to 100 feet (0 to 30 m). USES: suitable as dimension stone; quarried at Philipsville and Forfar for silica sand; alkali-silica reactive in Portland cement concrete. AGGREGATE SUITABILITY TESTING: PSV = 54-68, AAV = 4-15, $MgSO_4$ = 9-32, LA = 44-90, Absn = 1.6-2.6, BRD = 2.38-2.50, PN (Asphalt & Concrete) = 130-140.

March Formation (Lower Ordovician)

STRATIGRAPHY: lower formation of the Beekmantown Group. COMPOSITION: interbedded quartz sandstone, dolomitic quartz sandstone, sandy dolostone and dolostone. THICKNESS: 60 to 197 feet (18 to 60 m). USES: quarried extensively for aggregate in area of subcrop and outcrop; alkali-silica reactive in Portland cement concrete; lower part of formation is an excellent source of skid-resistant aggregate; suitable for use as facing stone and paving stone. AGGREGATE SUITABILITY TESTING: PSV = 55-60, AAV = 4-6, $MgSO_4$ = 1-17, LA = 15-38, Absn = 0.5-0.9, BRD = 2.61-2.65, PN (Asphalt & Concrete) = 110-150.

Oxford Formation (Lower Ordovician)

STRATIGRAPHY: upper formation of the Beekmantown Group. COMPOSITION: thin- to thick-bedded, microcrystalline to medium-crystalline, grey dolostone with thin shaly interbeds. THICKNESS: 200 to 335 feet (61 to 102 m). USES: quarried in the Brockville and Smith Falls areas and south of Ottawa for use as aggregate. AGGREGATE SUITABILITY TESTING: PSV = 47-48, AAV = 7-8, $MgSO_4$ = 1-4, LA = 18-23, Absn = 0.7-0.9, BRD = 2.74-2.78, PN (Asphalt & Concrete) = 105-120.

Rockcliffe Formation (Middle Ordovician)

STRATIGRAPHY: divided into lower member and upper (St. Martin) member. COMPOSITION: interbedded quartz sandstone and shale; interbedded shaly bioclastic limestone and shale predominating in upper member to the east. THICKNESS: 0 to 410 feet (0 to 125 m). USES: upper member has been quarried east of Ottawa for aggregate; lower member has been used as crushed stone; some high purity limestone beds in upper member may be suitable for use as fluxing stone and in lime production. AGGREGATE SUITABILITY TESTING: PSV = 58-63, AAV = 10-11, $MgSO_4$ = 12-40, LA = 25-28, Absn = 1.8-1.9, BRD = 2.55-2.62, PN (Asphalt & Concrete) = 122-440.

Shadow Lake Formation (Middle Ordovician)

STRATIGRAPHY: eastern Ontario - the basal unit of the Ottawa Group; central Ontario - overlain by the Simcoe Group. COMPOSITION: in eastern Ontario - silty and sandy dolostone with shale partings and minor interbeds of sandstone; in central Ontario - conglomer-

ates, sandstones, and shales. THICKNESS: eastern Ontario - 7 to 10 feet (2 to 3 m); central Ontario - 0 to 40 feet (0 to 12 m). USES: potential source of decorative stone; very limited value as aggregate source.

Gull River Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and Ottawa Group (eastern Ontario). In central and eastern Ontario the formation is subdivided into upper and lower members; west of Lake Simcoe it is presently subdivided into upper, middle and lower members. COMPOSITION: in central and eastern Ontario the lower member consists of alternating units of limestone, dolomitic limestone, and dolostone, the upper member consists of thin-bedded limestones with thin shale partings; west of Lake Simcoe the lower member is thin- to thick-bedded, interbedded, grey argillaceous limestone and buff to green dolostone, whereas the upper and middle members are dense microcrystalline limestones with argillaceous dolostone interbeds. THICKNESS: 23 to 204 feet (7 to 62 m). USES: quarried in the Lake Simcoe, Kingston, Ottawa, and Cornwall areas for crushed stone; rock from certain layers in eastern and central Ontario has proven to be alkali-reactive when used in Portland cement concrete (alkali-carbonate reaction). AGGREGATE SUITABILITY TESTING: PSV = 41-49, AAV = 8-12, $MgSO_4$ = 3-13, LA = 18-28, Absn = 0.3-0.9, BRD = 2.68-2.73, PN (Asphalt & Concrete) = 100-153.

Bobcaygeon Formation (Middle Ordovician)

STRATIGRAPHY: part of the Simcoe Group (central Ontario) and the Ottawa Group (eastern Ontario), subdivided into upper, middle and lower members; members in eastern and central Ontario are approximately equivalent. COMPOSITION: homogeneous, massive to thin-bedded fine-crystalline limestone with numerous shaly partings in the middle member. THICKNESS: 80 to 285 feet (24 to 87 m). USES: quarried at Brechin, Marysville, and in the Ottawa area for crushed stone; generally suitable for use as granular base course aggregate; rock from certain layers has been found to be alkali-reactive when used in Portland cement concrete (alkali-silica reaction). AGGREGATE SUITABILITY TESTING: PSV = 47-51, AAV = 14-23, $MgSO_4$ = 1-40, LA = 18-32, Absn = 0.3-2.4, BRD = 2.5-2.69, PN (Asphalt & Concrete) = 100-320.

Verulam Formation (Middle Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa Groups. COMPOSITION: fossiliferous, pure to argillaceous limestone interbedded with calcareous shale. THICKNESS: 105 to 230 feet (32 to 70 m). USES: quarried at Picton and Bath for use in cement manufacture; quarried for aggregate in Mara Township, Simcoe County and in the Belleville-Kingston area; may be unsuitable for use as aggregate in some areas because of its high shale content. AGGREGATE SUITABILITY TESTING: PSV = 43-44, AAV = 9-13, $MgSO_4$ = 4-45, LA = 22-29, Absn = 0.4-2.1, BRD = 2.59-2.70, PN (Asphalt & Concrete) = 120-255.

Lindsay Formation (Middle and Upper Ordovician)

STRATIGRAPHY: part of Simcoe and Ottawa Groups; in eastern Ontario is divisible into an unnamed lower member and the Eastview Member; in central Ontario is divisible into the Collingwood Member (equivalent to portions of the Eastview Member) and a lower member. COMPOSITION: in eastern Ontario the lower member is interbedded, very fine- to coarse-crystalline limestone with undulating shale partings and interbeds of dark grey calcareous shale, whereas the Eastview Member is an interbedded dark grey to dark brown calcareous shale and very fine- to fine-crystalline, petroliferous limestone; in central Ontario Collingwood Member is a black, calcareous shale whereas the lower member is a very fine- to coarse-crystalline, thin-bedded limestone with very thin, undulating shale partings. THICKNESS: 82 to 200 feet (25 to 61 m). USES: in eastern Ontario the lower member is used extensively for aggregate production; in central Ontario it is quarried at Picton, Ogden Point and Bowmanville for cement; may be suitable or unsuitable for use as concrete and asphalt aggregate. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 2-47, LA = 20-28, Absn = 0.4-1.3, BRD = 2.64-2.70, PN (Asphalt & Concrete) = 110-215.

Blue Mountain and Billings Formations (Upper Ordovician)

STRATIGRAPHY: central Ontario - Blue Mountain Formation includes the upper and middle members of the former Whitby Formation; eastern Ontario - Billings Formation is equivalent to part of the Blue Mountain Formation. COMPOSITION: the Blue Mountain Formation is blue-grey, noncalcareous shale; Billings Formation is dark grey to black, noncalcareous to slightly calcareous, pyritiferous shale with dark grey limestone laminae and grey siltstone interbeds. THICKNESS: Blue Mountain Formation - 140 to 200 feet (43 to 61 m); Billings Formation - 0 to 205 feet (0 to 62 m). USES: Billings Formation may be a suitable source for structural clay products and expanded aggregate; Blue Mountain Formation may be suitable for structural clay products.

Georgian Bay and Carlsbad Formations (Upper Ordovician)

COMPOSITION: in central Ontario the Georgian Bay Formation is composed of interbedded limestone and shale; in eastern Ontario the Carlsbad Formation is composed of interbedded shale, siltstone and bioclastic limestone; THICKNESS: Georgian Bay Formation is 300 to 560 feet (91 to 170 m); Carlsbad Formation - 0 to 610 feet (0 to 186 m). USES: Georgian Bay Formation is

used by several producers in Metropolitan Toronto area to produce brick and structural tile, as well as for making Portland cement; at Streetsville, expanded shale was used in the past to produce lightweight aggregate; Carlsbad Formation is used as a source material for brick and tile manufacturing, has potential as a lightweight expanded aggregate.

Queenston Formation (Upper Ordovician)

COMPOSITION: red, thin- to thick-bedded, sandy to argillaceous shale with green mottling and banding. THICKNESS: 400 to 500 feet (122 to 152 m). USES: there are several large quarries developed in the Queenston Formation in the Toronto-Hamilton region and one at Russell, near Ottawa; all extract shale for brick manufacturing; the Queenston Formation is the most important source material for brick manufacture in Ontario.

Whirlpool Formation (Lower Silurian)

STRATIGRAPHY: lower formation in the Cataract Group in the Niagara Penninsula and the Niagara Escarpment as far north as Duntroon. COMPOSITION: massive, medium- to coarse-grained, argillaceous white to light grey quartz sandstone with thin grey shale partings. THICKNESS: 0 to 25 feet (0 - 8 m). USES: building stone, flagstone.

Manitoulin Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs north of Stoney Creek. COMPOSITION: thin-bedded, blue-grey to buff-brown dolomitic limestones and dolostones. THICKNESS: 0 to 75 feet (0 to 23 m). USES: extracted for crushed stone in St. Vincent Township, Grey County, and for decorative stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: no data.

Cabot Head Formation (Lower Silurian)

STRATIGRAPHY: part of the Cataract Group, occurs throughout southern Ontario, south and north of the Niagara Escarpment. COMPOSITION: green, grey and red shales. THICKNESS: 50 to 60 feet (15 to 18 m); USES: potential source of coated lightweight aggregate and raw material for use in manufacture of brick and tile; lack of suitable exposures has limited its use.

Grimsby Formation

STRATIGRAPHY: upper formation of the Cataract Group, is identified on the Niagara Peninsula as far north as Clappison's Corners. COMPOSITION: interbedded sandstone and shale, mostly red. THICKNESS: 0 to 50 feet (0 to 15 m). USES: no present uses.

Thorold Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on the Niagara Peninsula. COMPOSITION: thick-bedded quartz sandstone. THICKNESS: 7 to 10 feet (2 - 3 m). USES: no present uses.

Neagha Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on the Niagara Peninsula. COMPOSITION: dark grey to green shale with minor interbedded limestone. THICKNESS: 0 to 5 feet (0 to 2 m). USES: no present uses.

Dyer Bay Formation (Middle Silurian)

STRATIGRAPHY: lower formation in the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: highly fossiliferous, impure dolostone. THICKNESS: 0 to 20 feet (0 to 6 m). USES: no present uses.

Wingfield Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula. COMPOSITION: olive green to grey shale with dolostone interbeds. THICKNESS: 0 to 36 feet (0 to 11 m). USES: no present uses.

St. Edmund Formation (Middle Silurian)

STRATIGRAPHY: part of the Clinton Group on Manitoulin Island and northernmost Bruce Peninsula, upper portion previously termed the Mindemoya Formation. COMPOSITION: pale grey to buff brown, micro- to medium-crystalline, thin- to medium-bedded dolostone. THICKNESS: 0 to 85 feet (0 to 26 m). USES: quarried for fill and crushed stone on Manitoulin Island. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-2, LA = 19-21, Absn = 0.6-0.7, BRD = 2.78-2.79, PN (Asphalt & Concrete) = 105.

Fossil Hill and Reynales Formations (Middle Silurian)

STRATIGRAPHY: part of Clinton Group; Fossil Hill Formation occurs in the northern part of the Niagara Escarpment and is approximately equivalent in part, to the Reynales Formation which occurs on the Niagara Peninsula and the Escarpment, as far north as the Forks of the Credit. COMPOSITION: Fossil Hill Formation is fine- to coarse-crystalline dolostone with high silica content; Reynales Formation is thin- to thick-bedded shaly dolostone and dolomitic limestone. THICKNESS: Fossil Hill Formation - 20 to 85 feet (6 to 26 m); Reynales Formation - 0 to 10 feet (0 to 3 m). USES: both formations quarried for aggregate with overlying Amabel and Lockport Formations. AGGREGATE SUITABILITY TESTING: (Fossil Hill Formation on Manitoulin Island) $MgSO_4$ = 41, LA = 29, Absn = 4.1, BRD = 2.45, PN (Asphalt & Concrete) = 370.

Irondequoit Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group on the Niagara Peninsula south of Waterdown. COMPOSITION: massive, coarse-crystalline crinoidal limestone. THICKNESS: 0 to 7 feet (0 to 2 m). USES: not significantly utilized.

Rochester Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group along the Niagara Peninsula. COMPOSITION: black to dark grey calcareous shale with numerous limestone lenses. THICKNESS: 15 to 60 feet (5 to 18 m). USES: not significantly utilized. AGGREGATE SUITABILITY TESTING: PSV = 69, AAV = 17, $MgSO_4$ = 95, LA = 19, Asbn = 2.2, BRD = 2.67, PN (Asphalt & Concrete) = 400.

Decew Formation (Middle Silurian)

STRATIGRAPHY: part of Clinton Group south of Waterdown along the Niagara Peninsula. COMPOSITION: sandy to shaly dolomitic limestone and dolostone. THICKNESS: 0 to 15 feet (0 to 5 m). USES: too shaly for high quality uses, but is quarried along with Lockport Formation in places. AGGREGATE SUITABILITY TESTING: PSV = 67, AAV = 15, $MgSO_4$ = 55, LA = 21, Absn = 2.2, BRD = 2.66, PN (Asphalt & Concrete) = 255.

Lockport and Amabel Formations (Middle Silurian)

STRATIGRAPHY: Lockport Formation occurs from Waterdown to Niagara Falls, subdivided into 3 formal members: Gasport, Goat Island and Eramosa Members and an informal member (the "Vinemount shale beds"); the stratigraphically equivalent Amabel Formation, found from Waterdown to Cockburn Island, is subdivided into Lions Head, Wiarton/Colpoy Bay, and Eramosa members. COMPOSITION: Lockport Formation is thin- to massive-bedded, fine- to medium-crystalline dolostone; Amabel Formation is thin bedded to massive, medium-crystalline dolostone with reef facies near Georgetown and on the Bruce Peninsula. THICKNESS: (Lockport/ Amabel) 10 to 130 feet (3 to 40 m). USES: both formations have been used to produce lime, crushed stone, concrete aggregate, and building stone throughout their area of occurrence, and are a resource of provincial significance. AGGREGATE SUITABILITY TESTING: PSV = 36-49, AAV = 10-17, $MgSO_4$ = 2-6, LA = 25-32, Absn = 0.4-1.54, BRD = 2.61-2.81, PN (Asphalt & Concrete) = 100-105.

Guelph Formation (Middle Silurian)

STRATIGRAPHY: exposed on the Niagara Escarpment from the Niagara River to the tip of the Bruce Peninsula, mostly present in the subsurface of southwestern Ontario. COMPOSITION: micro-crystalline to medium-crystalline, thick-bedded, soft, porous dolostone, characterized in places by extensive vuggy, porous reefal facies of high chemical purity. THICKNESS: 100 to 170 feet (30 to 52 m). USES: some areas appear soft and unsuitable for use in the production of load-bearing aggregate; this unit requires additional testing to fully establish its aggregate suitability; main use is for dolomitic lime for cement manufacture; quarried near Hamilton and Guelph.

Salina Formation (Upper Silurian)

STRATIGRAPHY: present in the subsurface of southwestern Ontario; rarely exposed at the surface. COMPOSITION: grey and maroon shale, brown dolostone and, in places, salt, anhydrite and gypsum; consists predominantly of evaporitic rich material with up to eight units identifiable. THICKNESS: 370 to 600 feet (113 to 183 m). USES: gypsum mines at Hagersville, Caledonia, and Drumbo; salt is mined at Goderich and Windsor, and is produced from brine wells at Amherstburg, Windsor and Sarnia.

Bertie and Bass Islands Formations (Upper Silurian)

STRATIGRAPHY: Bertie Formation found in southern Niagara Peninsula; Bass Islands Formation, the Michigan Basin equivalent of the Bertie Formation, does not significantly outcrop in Ontario but is present in the subsurface in southwestern Ontario; Bertie Formation represented by Oatka, Falkirk, Scajaquanda, Williamsville, and Akron Members. COMPOSITION: medium- to massive-bedded, micro-crystalline, brown dolostone with shaly partings. THICKNESS: 45 to 160 feet (14 to 49 m). USES: quarried for crushed stone on the Niagara Peninsula at Fort Erie, Cayuga, Hagersville and Dunnville; shaly intervals are unsuitable for use as high specification aggregate because of low freeze-thaw durability; has also been extracted for lime. AGGREGATE SUITABILITY TESTING: PSV = 46-49, AAV = 8-11, $MgSO_4$ = 4-19, LA = 14-23, Absn = 0.8-2.8, BRD = 2.61-2.78, PN (Asphalt & Concrete) = 102-120.

Oriskany Formation (Lower Devonian)

STRATIGRAPHY: basal Devonian clastic unit, found in Niagara Peninsula. COMPOSITION: thick- to massive-bedded, coarse-grained, grey-yellow sandstone. THICKNESS: 0 to 15 feet (0 to 5 m). USES: has been quarried for silica sand, building stone, and armour stone; may be acceptable for use as rip rap, and well cemented varieties may be acceptable for some asphaltic products. AGGREGATE SUITABILITY TESTING: (of a well cemented variety of the formation) PSV = 64, AAV = 6, $MgSO_4$ = 2, LA = 29, Absn = 1.2-1.3, BRD = 2.55, PN (Asphalt & Concrete) = 107.

Bois Blanc Formation (Lower Devonian)

STRATIGRAPHY: Springvale Sandstone Member forms the lower portion of formation. COMPOSI-

TION: a cherty limestone with shale partings and minor interbedded dolostones; Springvale Sandstone Member is a medium- to coarse-grained, green glauconitic sandstone with interbeds of limestone, dolostone and brown chert. THICKNESS: 10 to 130 feet (3 to 40 m). USES: quarried at Hagersville, Cayuga, and Port Colborne for crushed stone; material generally unsuitable for concrete aggregate because of high chert content. AGGREGATE SUITABILITY TESTING: PSV = 48-53, AAV = 3-7, $MgSO_4$ = 3-18, LA = 15-22, Absn = 1.3-2.8, BRD = 2.50-2.70, PN (Asphalt & Concrete) = 102-290.

Onondaga Formation (Middle Devonian)

STRATIGRAPHY: correlated to part of the Detroit River Group; occurs on the Niagara Peninsula from Simcoe to Niagara Falls; contains the Edgecliff, Clarence, and Moorehouse Members. COMPOSITION: medium-bedded, fine- to coarse-grained, dark grey-brown or purplish-brown, variably cherty limestone. THICKNESS: 60 to 82 feet (18 to 25 m) USES: quarried for crushed stone on the Niagara Peninsula at Welland and Port Colborne; high chert content makes much of the material unsuitable for use as concrete aggregate and asphaltic concrete; has been used as a raw material in cement manufacture. AGGREGATE SUITABILITY TESTING: (Clarence and Edgecliff Members) $MgSO_4$ = 1-6, LA = 16.8-22.4, Absn = 0.5-1.1, PN (Asphalt & Concrete) = 190-276.

Amherstburg Formation (Middle Devonian)

STRATIGRAPHY: part of Detroit River Group; correlated to Onondaga Formation in Niagara Penninsula; contains Sylvania Sandstone Member and Formosa Reef Limestone. COMPOSITION: bituminous, bioclastic, stromatoporoid-rich limestone and dolostone with grey chert nodules; Formosa Reef Limestone is high purity (calcium rich) limestone; Sylvania Sandstone Member is quartz sandstone. THICKNESS: 0 to 165 feet (0 to 50 m); Formosa Reef Limestone up to 85 feet (26 m). USES: cement manufacture, agricultural lime, aggregate. AGGREGATE SUITABILITY TESTING: PSV = 57, AAV = 19, $MgSO_4$ = 9-35, LA = 26-52, Absn = 1.1-6.4, BRD = 2.35-2.62, PN (Asphalt & Concrete) = 105-300.

Lucas Formation (Middle Devonian)

STRATIGRAPHY: part of the Detroit River Group in southwestern Ontario; includes the Anderdon Member which, in the Woodstock Beachville area, may constitute the bulk of the formation. COMPOSITION: light brown or grey-brown dolostone with bituminous laminations and minor chert; Anderdon Member consists of very high purity (calcium-rich) limestone. THICKNESS: 130 to 246 feet (40 to 75 m). USES: most important source of high-purity limestone in Ontario; used as calcium lime for metallurgical flux and for the manufacture of chemicals; rock of lower purity is used for cement manufacture, agricultural lime and aggregate; Anderdon Member is quarried at Amherstburg for crushed stone. AGGREGATE SUITABILITY TESTING: PSV = 46-47, AAV = 15-16, $MgSO_4$ = 2-60, LA = 22-47, Absn = 1.1-6.5, BRD = 2.35-2.40, PN (Asphalt & Concrete) = 110-160.

Dundee Formation (Middle Devonian)

STRATIGRAPHY: few natural outcrops, largely in the subsurface of southwestern Ontario. COMPOSITION: fine- to medium-crystalline, brownish-grey, medium- to thick-bedded, dolomitic limestone with shaly partings sandy layers, and chert in some areas. THICKNESS: 50 to 100 feet (15 to 30 m). USES: quarried near Port Dover and on Pelee Island for crushed stone; used at St. Marys as a raw material for Portland cement. AGGREGATE SUITABILITY TESTING: $MgSO_4$ = 1-28, LA = 22-46, Absn = 0.6-6.8, PN (Asphalt & Concrete) = 125-320.

Marcellus Formation (Middle Devonian)

STRATIGRAPHY: subsurface unit, mostly found below Lake Erie and extending into the eastern U.S.A., pinches out in the Port Stanley area. COMPOSITION: black, bituminous shales. THICKNESS: 0 to 15 feet (0 to 5 m). USES: no present uses.

Bell Formation (Middle Devonian)

STRATIGRAPHY: lowest formation of the Hamilton Group, no outcrop in Ontario. COMPOSITION: soft blue and grey calcareous shale. THICKNESS: 0 to 30 feet (0 to 9 m). USES: no present uses.

Rockport Quarry Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group; no outcrop in Ontario. COMPOSITION: grey-brown, very fine-grained limestone with occasional shale layers. THICKNESS: 0 to 20 feet (0 to 6 m). USES: no present uses.

Arkona Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: blue-grey, plastic, clay shale with occasional thin and laterally discontinuous limestone lenses. THICKNESS: 15 to 120 feet (5 to 37 m). USES: has been extracted at Thedford and near Arkona for the production of drainage tile.

Hungry Hollow Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: grey crinoidal limestone and soft, fossiliferous calcareous shale. THICKNESS: 0 to 6 feet (0 to 2 m). USES: suitable for some crushed stone and fill with selective quarrying. AGGREGATE SUITABILITY TESTING: No data.

Widder Formation (Middle Devonian)

STRATIGRAPHY: part of the Hamilton Group. COMPOSITION: mainly soft, grey, fossiliferous calcareous shale interbedded with blue-grey, fine-grained fossiliferous limestone. THICKNESS: 0 to 45 feet (0 to 14 m). USES: no present uses.

Ipperwash Formation (Middle Devonian)

STRATIGRAPHY: upper formation of the Hamilton Group; very limited distribution. COMPOSITION: medium- to coarse-grained, grey-brown, bioclastic limestone. THICKNESS: 5 to 45 feet (2-14 m). USES: no present uses.

Kettle Point Formation (Upper Devonian)

STRATIGRAPHY: occurs in a band between Sarnia and Erieau; small part overlain by Port Lambton Group rocks in extreme northwest. COMPOSITION: black, highly fissile, organic-rich shale with minor interbeds of grey-green silty shale. THICKNESS: 0 to 200 feet (0 to 61 m). USES: possible source of fill; possible source of material for use as sintered lightweight aggregate.

Bedford Formation (Upper Devonian)

STRATIGRAPHY: lower formation of the Port Lambton Group. COMPOSITION: soft, grey shale. THICKNESS: 0 to 108 feet (0 to 33 m). USES: no present uses.

Berea Formation (Upper Devonian)

STRATIGRAPHY: middle formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: grey, fine- to medium-grained sandstone, often dolomitic and interbedded with grey shale and siltstone. THICKNESS: 0 to 197 feet (0 to 60 m). USES: no present uses.

Sunbury Formation (Upper Devonian)

STRATIGRAPHY: upper formation of the Port Lambton Group; not known to occur at surface in Ontario. COMPOSITION: black shale. THICKNESS: 0 to 66 feet (0 to 20 m). USES: no present uses.

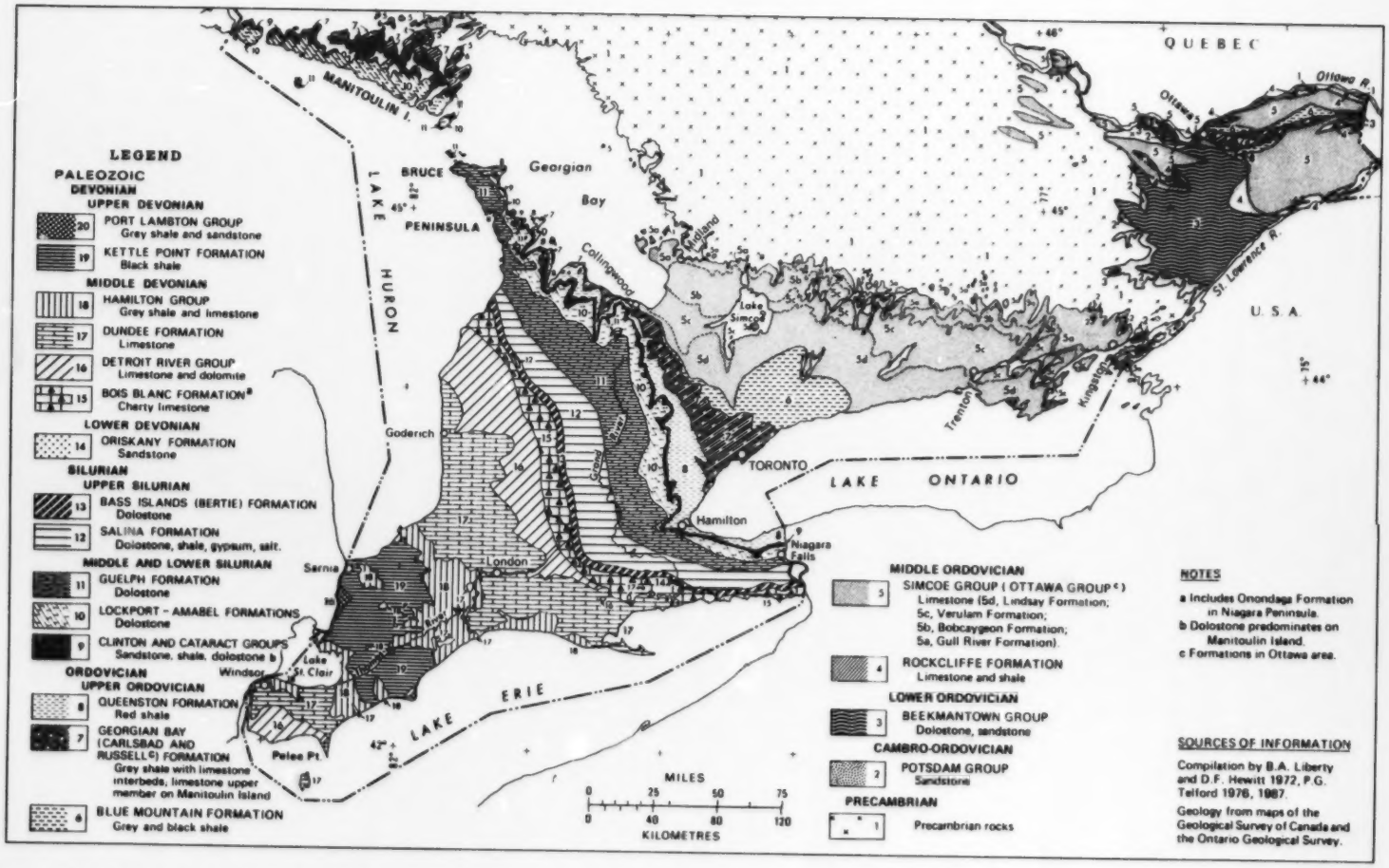


Figure D1. Bedrock Geology of Southern Ontario.

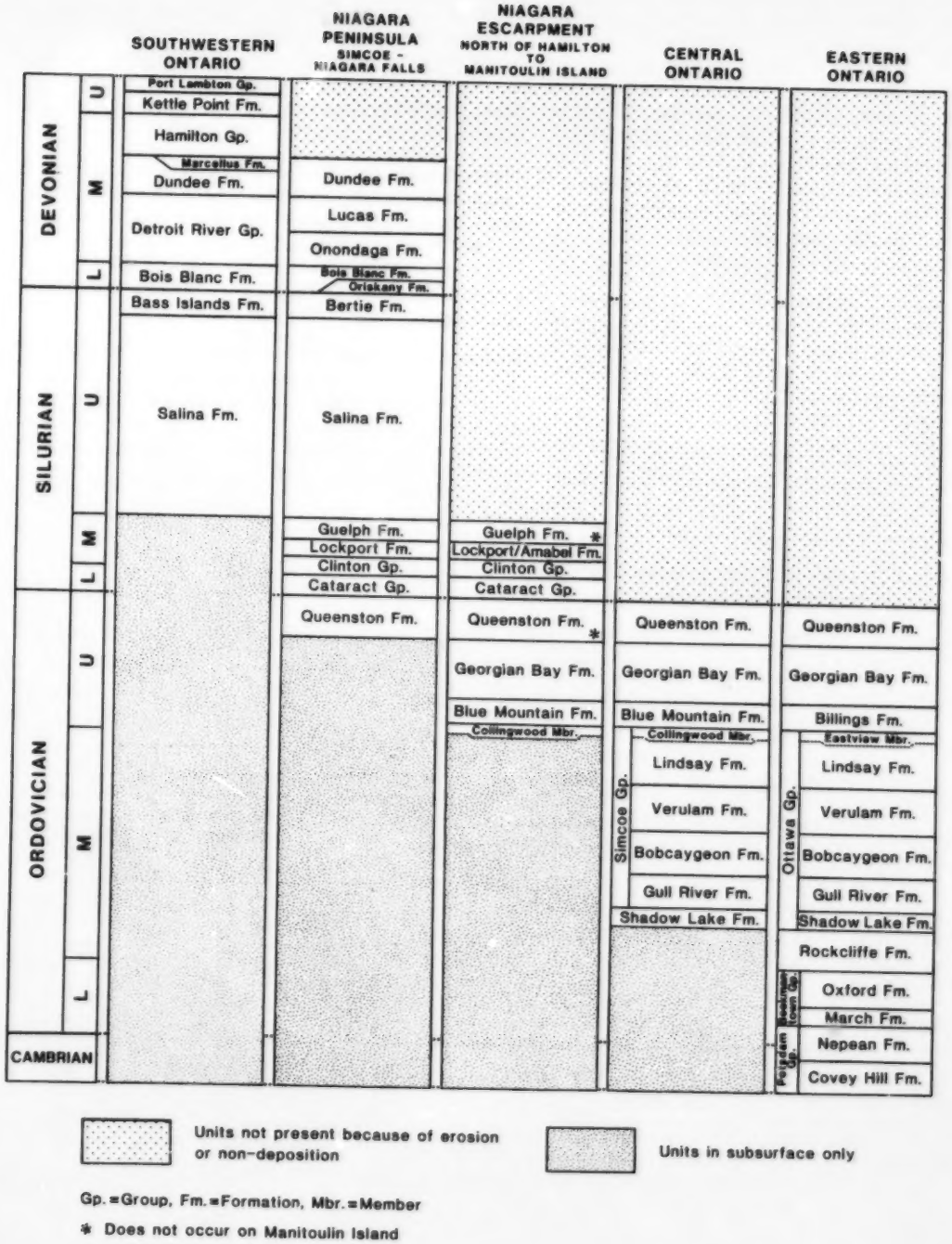


Figure D2. Exposed Paleozoic Stratigraphic Sequences in Southern Ontario
(adapted from: Bezys, R. K., and Johnson, M.D. 1988. The geology of the Paleozoic formations utilized by the limestone industry of Ontario; The Canadian Mining and Metallurgical Bulletin v.81, no.912, p.49–58).

Appendix E — Aggregate Quality Test Specifications

Four types of aggregate quality tests are often performed by the Ontario Ministry of Transportation on sampled material. A description of Table E1 and the specification limits for each test are given in this appendix. Although a specific sample meets or does not meet the specification limits for a certain product, it may or may not be acceptable for that use based on field performance. Additional quality tests other than the four major tests listed in this appendix can be used to determine the suitability of an aggregate. The tests are performed by the Soils and Aggregates Section, Engineering Materials Office, Ontario Ministry of Transportation.

Absorption capacity: Related to the porosity of the rock types of which an aggregate is composed. Porous rocks are subject to disintegration when absorbed liquids freeze and thaw, thus decreasing the strength of the aggregate.

Los Angeles Abrasion and Impact test: This test measures the resistance to abrasion and the impact strength of aggregate. This gives an idea of the breakdown that can be expected to occur when an aggregate is stockpiled, transported, and placed. Values less than about 35% indicate potentially satisfactory performance for most concrete and asphalt uses. Values of more than 45% indicate that the aggregate may be susceptible to excessive breakdown during handling and placing.

Magnesium Sulphate Soundness test: This test is designed to simulate the action of freezing and thawing on aggregates. Those aggregates which are susceptible to freezing and thawing will usually break down and give high losses in this test. Values greater than about 12 to 15% indicate potential problems for concrete and asphalt coarse aggregate.

Petrographic examination: Individual aggregate particles in a sample are divided into categories good, fair, poor, and deleterious, based on their rock type (petrography) and knowledge of past field performance. A petrographic number (PN) is calculated. The higher the PN, the lower the quality of the aggregate.

TABLE E1. SELECTED QUALITY REQUIREMENTS FOR MAJOR AGGREGATE PRODUCTS.

	TYPE OF TEST				
	COARSE AGGREGATE				FINE AGGREGATE
TYPE OF MATERIAL	Petrographic Number Maximum	Magnesium Sulphate Soundness – Max. % Loss	Absorption Maximum %	Los Angeles Abrasion Maximum % Loss	Magnesium Sulphate Soundness Maximum % Loss
Granular Base A	200	–	–	60	–
16 mm Crushed Type 'A'	160	–	–	35	–
16 mm Crushed Type 'B'	200	–	–	60	–
Granular Subbase B	250	–	–	–	–
Granular Subbase C	250	–	–	–	–
Granular Subbase D	–	–	–	–	–
Hot Mix – HL 1	100	5	1.0	15	16
Hot Mix – HL 2	–	–	–	–	20
Hot Mix – HL 3	135	12	1.75	35	16
Hot Mix – HL 4	160	12	2.0	35	20
Hot Mix – HL 8	160	15	2.0	35	20
Structural Concrete and Concrete Base	140	12	2.0	35	16
Pavement Concrete and Exposed Structure Deck	125	12	2.0	35	16

(Ministry of Transportation Forms 1002, 1003 and 1010)

CONVERSION FACTORS FOR MEASUREMENTS IN ONTARIO GEOLOGICAL SURVEY PUBLICATIONS

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709 7	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 02	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.308 0	cubic yards	1 cubic yard	0.764 555	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 96	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 75	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 62	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 908 8**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

MAPS
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CARTES
OMISES